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Subseries of Lecture Notes in Computer Science

Jean-Claude Heudin (Ed.)

Virtual Worlds

First International Conference, VW'98
Paris, France, July 1998
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Preface

1 Introduction

Imagine a virtual world with digital creatures that looks like real life, sounds like real life, and even feels like real life. Imagine a virtual world not only with nice three-dimensional graphics and animations, but also with realistic physical laws and forces. This virtual world could be familiar, reproducing some parts of our reality, or unfamiliar, with strange "physical" laws and artificial life forms.

As a researcher interested in the sciences of complexity, the idea of a conference about virtual worlds emerged from frustration. In the last few years, there has been an increasing interest in the design of artificial environments using image synthesis and virtual reality. The emergence of industry standards such as VRML [1] is an illustration of this growing interest. At the same time, the field of Artificial Life has addressed and modeled complex phenomena such as self-organization, reproduction, development, and evolution of artificial life-like systems [2]. One of the most popular works in this field has been Tierra designed by Tom Ray: an environment producing synthetic organisms based on a computer metaphor of organic life in which CPU time is the "energy" resource and memory is the "material" resource [3]. Memory is organized into informational patterns that exploit CPU time for self-replication. Mutation generates new forms, and evolution proceeds by natural selection as different creatures compete for CPU time and memory space.

However, very few works have used an Artificial Life approach together with Virtual Reality, or at least with advanced three-dimensional graphics. Karl Sims was probably one of the first researchers working in this direction. He designed a flexible genetic system to specify solutions to the problem of being a "creature" built of collections of blocks, linked by flexible joints powered by "muscles" controlled by circuits based on an evolvable network of functions [4]. Sims embedded these "block creatures" in simulations of real physics, such as in water or on a surface. These experiments produced a bewildering and fascinating array of creatures, like the swimming "snake" or the walking "crab". Demetri Terzopoulos and his colleagues have also created a virtual marine world inhabited by realistic artificial fishes [5]. They have emulated not only the appearance, movement, and behavior of individual animals, but also the complex group behaviors evident in many aquatic ecosystems. Each animal was modeled holistically as an autonomous agent situated in a simulated physical world.

Considering recent advances in both Artificial Life and Virtual Reality, catalyzed by the development of Internet , a unified approach seemed to be one of the most promising trend for the synthesis of realistic and imaginary virtual worlds. Thus, the primary goal of this conference was to set up an opportunity for researchers from both fields to meet and exchange ideas.

In July 1998, the first international conference on virtual worlds was held at the International Institute of Multimedia. It brought together scientists involved in Virtual Reality, Artificial Life, Multi-agent Systems, and other fields of computer science and electronic art, all of whom share a common interest in the synthesis of digital worlds

on computers. The diversity and quality of the work reported herein reflects the impact that this new trend of research has had on the scientific community.

2 The Proceedings

The production of these proceedings was a major task, involving all the authors and reviewers. As the editor, I have managed the proceedings in a classical way. Every contribution that was accepted for presentation at the conference is in the proceedings. The program committee felt that these papers represented mature work of a level suitable for being recorded, most of them without modification, some of them requiring modifications to be definitively accepted. Besides the classical goal of a proceedings volume, the idea was to recapture in print the stimulating mix of ideas and works that were presented. Therefore, the papers are organized to reflect their presentation at the conference. There were three invited plenary speakers: Nadia Thalmann, Jeffrey Ventrella, and Yaneer Bar-Yam. Two of them choose to provide a printed version of their lecture. There were nine sessions, most of them in parallel, for a total of 36 papers in all, recorded here roughly in the order in which they were presented.

The material covered in these proceedings is diverse and falls naturally into a number of categories: Virtual Reality, Artificial Life, Multi-agent Systems, Complexity, Applications of Virtual Worlds, and last but not least, Virtual Worlds and Art. This collection of papers constitutes a good sample of works that appear necessary if we want to design large and realistic virtual worlds on the Internet in the near future.

3 Acknowledgments

Many people and groups contributed to the success of the conference. My sincere thanks go out to all of them. I would like to thank first all the distinguished authors who contributed to this volume for their willingness to share the excitement of a new enterprise. The committee which selected the papers included the editor along with :

Michael *Best* (MIT Media Lab., USA),
Yaneer *Bar-Yam* (NECSI, USA),
Bruce *Blumberg* (MIT Media Lab., USA),
Eric *Bonabeau* (Santa Fe Institute, USA),
Terry *Bossomaier* (Charles Sturt University, Australia),
Philippe *Coiffet* (Versailles & St Quentin en Yvelines University, France),
Bruce *Damer* (Contact Consortium, USA),
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Hiroaki *Kitano* (Sony Computer Science Lab., Japan),

Jean *Louchet* (ENSTA, France),
Nadia *Magnenat-Thalmann* (University of Geneva, Switzerland),
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Demetri *Terzopoulos* (University of Toronto, Canada),
Jeffrey *Ventrella* (Rocket Science Games, USA),
Marie-Luce *Viaud* (INA, France),
Claude *Vogel* (Semio, USA),
Chris *Winter* (British Telecom, UK).

I am also grateful to Silicon Graphics (official partner of the conference), Canal+ Virtuel, and Softimage for their financial support. Special thanks are due to the New England Complex System Institute, the EvoNet Network of Excellence in Evolutionary Computation, the Contact Consortium, and the International Society on Virtual Systems and Multimedia for their support.

I had a significant help for organizing and running this conference. Most of the staff of the International Institute of Multimedia fall under this category. First and foremost, I have to thank Claude Vogel who was encouraging and supporting me at every step of the project. Monika Siejka performed an enormous amount of work. She was effectively my co-organizer. It was a pleasure to work with Monika. Olga Kisseleva was another co-organizer. Olga was in charge of the artistic part of the conference. Thanks are also due to Sophie Dussault and Sylvie Perret for their help. Finally, all the staff of the Pôle Universitaire Léonard de Vinci were once again a pleasure to work with.

4 Conclusion

The terms "virtual worlds" generally refer to Virtual Reality applications or experiences. In this volume, I have extended the use of these terms to describe experiments that deal with the idea of synthesizing digital worlds on computers. Thus, Virtual Worlds (VW) could be defined as the study of computer programs that implement digital worlds with their own "physical" and "biological" laws. Constructing such complex artificial worlds seems to be extremely difficult to do in any sort of complete and realistic manner. Such a new discipline must benefit from a large amount of work in various fields: Virtual Reality, Artificial life, Cellular Automata, Evolutionary Computation, Simulation of Physical Systems, and more. Whereas Virtual Reality has largely concerned itself with the design of three-dimensional graphical spaces and Artificial Life with the simulation of living organisms, VW is concerned with the simulation of worlds and the synthesis of digital universes.

This approach is something broader and more fundamental. Throughout the natural world, at any scale, from particles to galaxies, one can observe phenomena of great complexity. Research done in traditional sciences such as biology and physics has

shown that the basic components of complex systems are quite simple. It is now a crucial problem to elucidate the universal principles by which large numbers of simple components, acting together, can self-organize and produce the complexity observed in our universe [6]. Therefore, VW is also concerned with the formal basis of synthetic universes. In this framework, the synthesis of virtual worlds offers a new approach for studying complexity.

I hope that the reader will find in this volume many motivating and enlightening ideas. My wish is that this book will contribute to the development and further awareness of the new and fascinating field of Virtual Worlds. As of now, the future looks bright.

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May 1998 Jean-Claude Heudin

Table of Contents

Virtual Reality (3)

Invited Paper

Artificial Life

Multi-Agent

Complexity

Applications (1)

Applications (2)

Virtual Worlds and Art

Real Face Communication in a Virtual World

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Abstract. This paper describes an efficient method to make an individual face for animation from several possible inputs and how to use this result for a realistic talking head communication in a virtual world. We present a method to reconstruct 3D facial model from two orthogonal pictures taken from front and side views. The method is based on extracting features from a face in a semiautomatic way and deforming a generic model. Texture mapping based on cylindrical projection is employed using a composed image from the two images. A reconstructed head is animated immediately and is able to talk with given text, which is transformed to corresponding phonemes and visemes. We also propose a system for individualized face-to-face communication through network using MPEG4.

Keywords: Cloning, orthogonal pictures, DFFD, texture mapping, talking head, visemes, animation

1. Introduction

Individualized facial communication is becoming more important in modern computer-user interfaces. To visualize ones own face in a virtual world and let people talk with given input, such as text or video, is now a very attractive research area. With the fast pace in computing, graphics and networking technologies, real-time face-to-face communication in a virtual world is now realizable. It is necessary to reconstruct an individual head in an efficient way to decrease data transmission size, and send few parameters for real-time performance.

Cloning a real person's face has practical limitations in the sense of time, simple equipment and realistic shape. We present our approach to clone a real face from two orthogonal views, emphasizing accessibility for anybody with low price equipment. Our method to give animation structure on a range data from a laser scanner or stereoscopic camera is also described, but not in detail. This is because of the high price of this equipments. Therefore, it may not be a very practical idea to make use of them. The main idea is to detect feature points and modify a generic model with

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animation structure. After creating virtual clones, we can use them to animate and talk in a virtual world.

The organization of this paper is as follows. We give a review in Section 2 with classification for existing methods to get a realistic face reconstruction and talking head. In Section 3, we describe the idea of a system for individualized face-to-face communication through a network and our system for creating/animating talking head with given text. Section 4 is dedicated to the reconstruction process from feature detection to texture mapping and then the detailed process for talking head is explained in Section 5. Finally conclusion is given.

2. Related Work

2.1. Face Cloning for Animation

There have been many approaches to reconstruct a realistic face in a virtual world. There are many possible ways such as using a plaster model [12][1], or interactive deformation and texture mapping [2][15], which are time-consuming jobs. More efficient methods are classified into four categories.

Laser Scanning In range image vision system some sensors, such as laser scanners, yield range images. For each pixel of the image, the range to the visible surface of the objects in the scene is known. Therefore, spatial location is determined for a large number of points on this surface. An example of commercial 3D digitizer based on laser-light scanning is Cyberware Color Digitizer™ [14].

Stripe Generator As an example of structured light camera range digitizer, a light striper with a camera and stripe pattern generator can be used for face reconstruction with relatively cheap equipment compared to laser scanners. With information of positions of projector and camera and stripe pattern, a 3D shape can be calculated. Proesmans et al. [13] shows a good dynamic 3D shape using a slide projector, by a frame-by-frame reconstruction of a video. However, it is a passive animation and new expressions cannot be generated.

Stereoscopy A distance measurement method such as stereoscopy can establish the correspondence at certain characteristic points. The method uses the geometric relation over stereo images to recover the surface depth. C3D 2020 capture system [3] by the Turing Institute produces many VRML models using stereoscopy method.

Most of the above methods concentrate on recovering a good shape, but the biggest drawback is that they provide only the shape without structured information. To get a structured shape for animation, the most typical way is to modify an available generic model with structural information such that eyes, lips, nose, hair and so on. Starting with a structured facial mesh, Lee et al. [13] developed algorithms that automatically construct functional models of the heads of human subjects from laser-

scanned range and reflection data [14]. However, the approach based on 3D digitization to get range data often requires special purpose high-cost hardware. Therefore, a common way of creating 3D objects is the reconstruction from 2D photo information, which is accessible at a low price.

Modification with Feature Points on Pictures There are faster approaches to reconstruct a face shape from only a few pictures of a face. In this method, a generic model with an animation structure in 3D is provided in advance and a limited number of feature points. These feature points are the most characteristic points to recognize people, detected either automatically or interactively on two or more orthogonal pictures, and the other points on the generic model are modified by a special function. Then 3D points are calculated by just combining several 2D coordinates. Kurihara and Arai [9], Akimoto et al. [4], Ip and Yin [7], and Lee et al. [16] use an interactive, semiautomatic or automatic methods to detect feature points and modify a generic model. Some have drawbacks such as too few points to guarantee appropriate shape from a very different generic head or accurate texture fitting, or automatic methods, which are not robust enough for satisfactory result, like simple filtering and texture image generation using simple linear interpolation blending.

2.2. Talking Head

There are two approaches for the synthesis of talking heads. Pearce et al. [17] have used an approach to create an animation sequence with the input being a string of phonemes corresponding to the speech. In this case, the face is represented by a 3D model and animated by altering the position of various points in the 3D model. A the more recent work of Cohen and Massaro [18], english text is used as the input to generate the animation. The alternative is the image-based morphing approach. Ezzat and Poggio [19] have proposed a method of concatenating a collection of images, using a set of optical flow vectors to define the morphing transition paths, to create an animated talking head. In another recent work of Cosatto and Graf [20], they have proposed an automatic method of extracting samples from a video sequence of a talking person using image recognition techniques. In this case, the face image is being partitioned into several facial parts and later combined to generate a talking head. They focused to reduce the number of samples that are needed and photo-realistic movements of lips.

2.3. Shared Virtual World

There have been numerous works being done on the topic of shared virtual environments. In most of these works [23][24][25], each user is represented by a fairly simple embodiment, ranging from cube-like appearances, non-articulated human-like or cartoon-like avatars to articulated body representations using rigid body segments. In the work of Pandzic et al. [26], a fully articulated body with skin deformations and facial animation is used. However, none of these works discussed

about the process of creating individual face model in an efficient manner. In other words, each individual face model usually takes hours of effort to complete. The MPEG-4 framework [30] under standardization can be used to achieve a low bandwidth face-to-face communication between two or more users, using individualized faces.

3. System Overview

In networked collaborative virtual environments, each user can be represented by a virtual human with the ability to feel like "being together" by watching each other's face. Our idea for face-to-face communication through a network is to clone a face with texture as starting process and send the parameters for the reconstruction of the head model to other users in the virtual environment. After this, only animation and audio parameters are sent to others in real time to communicate. The actual facial animation can be done on a local host and all the users can see every virtual human's animation. This provides a low bandwidth solution for having a teleconference between distanced users, compared to traditional video conferencing, which sends video stream in real time through network. At the same time, it is able to retain a high level of realism with individualized textured 3D head.

The general idea of a system for individualized face-to-face communication through network is shown in Fig. 1. There are two hosts, host1 and host2. Each host has a generic model and a program to clone a person from a given input such as two orthogonal pictures or range data. A person in host1 is reconstructed with pictures or range data obtained in any range data equipment. The parameters for reconstruction will be sent to host2 through network. They are texture image data, texture coordinates and either modification parameters or geometric position data for points on a 3D head surface. The same procedure happens in host2. Finally, both host1 and host2 have two 3D heads which are textured. Although we send a texture image, which takes large bandwidth, it is only one time process for reconstruction. After this process, only animation parameters and audio data are sent to another host through network. With animation parameters given, each host will animate two heads in their own platforms.

The part of this system showing the proceedure of producing an individualized talking head is shown in Fig. 2. We reconstruct a real face from a given input. For reconstruction, only some points (so called feature points) are extracted from front and side views or only from front view if range data is available and then a generic model is modified. After reconstructing a head, it is ready to animate with given animation parameters. We use this model and apply it to talking head, which has animation abilities given text input. The input speech text is transformed to corresponding phonemes and animation parameters, so called visemes. In addition, expression parameters are added to produce final face with audio output.

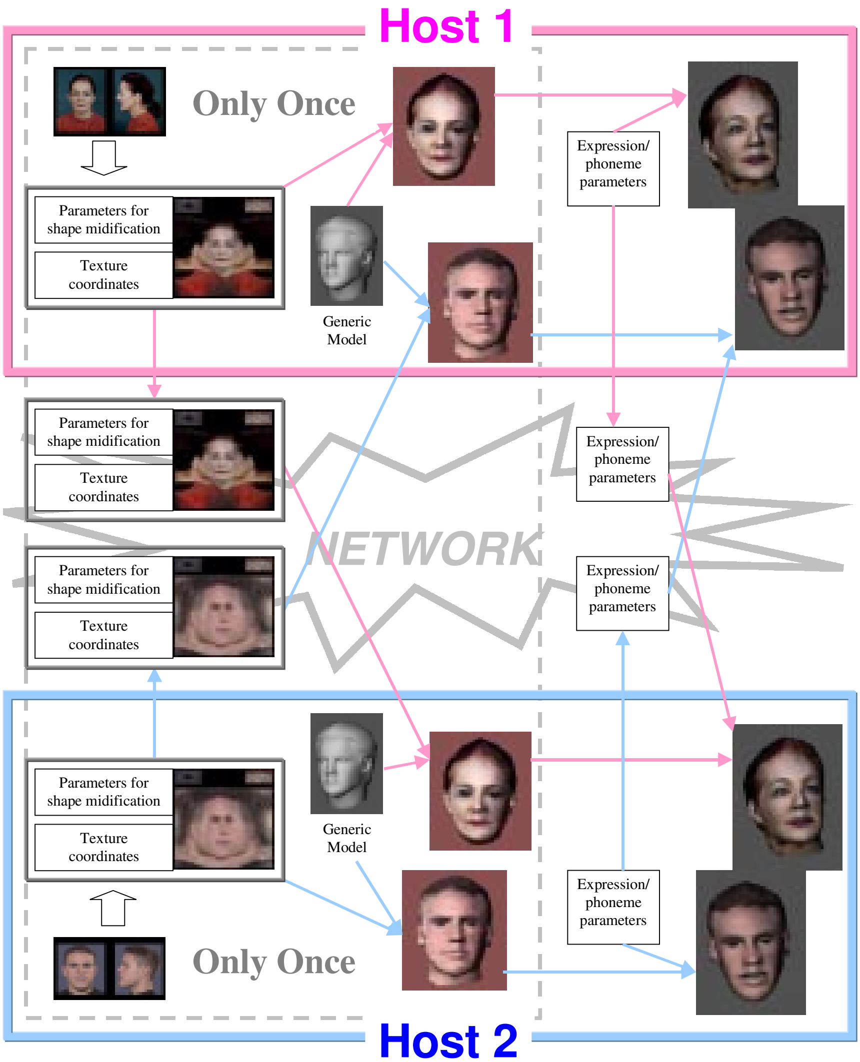


Fig. 1. A system overview for individualized face-to-face communication through network.

4. Face Cloning

We reconstruct a face from two kinds of input, such as an orthogonal picture or range data in VRML format. The main idea is to modify a generic animation model with detected feature points and apply automatic texture mapping. In this paper, we focus on orthogonal picture input rather than range data input since the approach based on 3D digitization to get a range data often requires special purpose (and high-cost) hardware and the process is quite similar to orthogonal picture case.

We consider hair outline, face outline and some interior points such as eyes, nose, lips, eyebrows and ears as feature points.

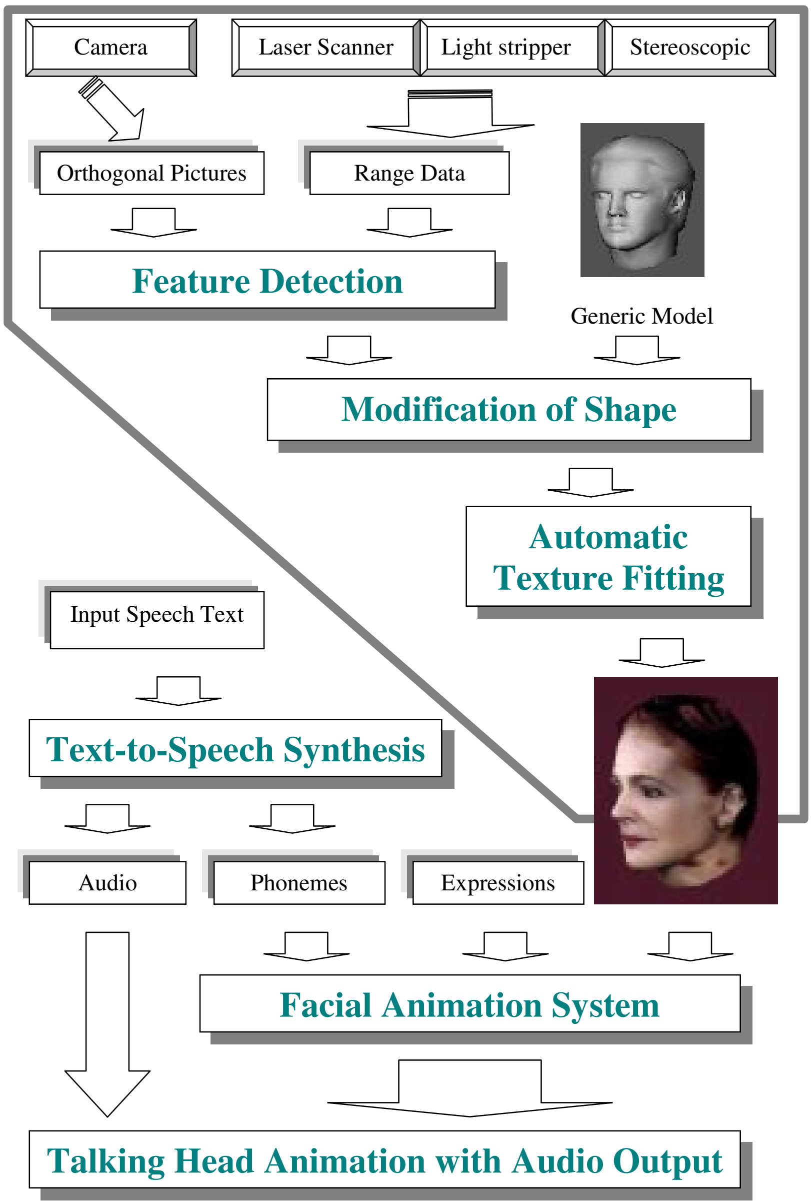


Fig. 2. Overall structure for individualized talking head.

4.1. Preparation and Normalization

First, we prepare two 2D wire frames composed of feature points with predefined relations for front and side views. The frames are designed to be used as an initial position for the snake method later. Then we take pictures from front and side views of the head. The picture is taken with maximum resolution and the face is in the neutral expression and pose.

To make the head heights of side and front views the same, we measure them, and choose one point from each view to matching them with corresponding points in prepared frame. Then we use transformation (scaling and translation) to bring the pictures to the wire frame coordinate, overlaying frames on pictures.

4.2. Feature Detection

We provide an automatic feature point extraction method with an interface for interactive correction when needed. There are methods to detect them just using special background information and predefined threshold [4][7] and then use an edge detection method and apply threshold again. In addition, image segmentation by clustering method is used [4]. However, it is not very reliable since the boundary between hair and face and chin lines are not easy to detect in many cases. Moreover color thresholding is too sensitive and depends on each individual's facial image and therefore requires many trials and experiments. We therefore use a structured snake, which has functionality to keep the structure of contours. It does not depend much on the background color and is more robust than simple thresholding method.

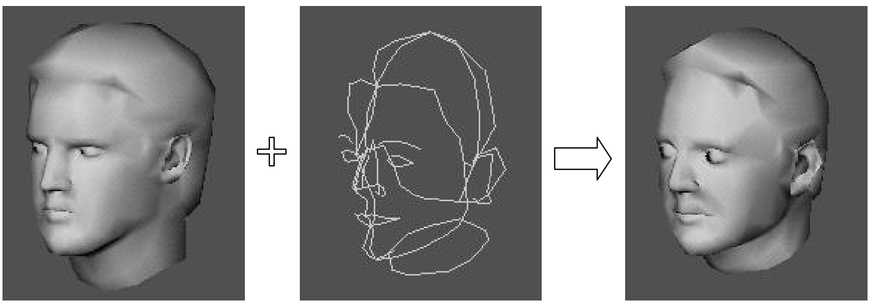
Structured Snake First developed by Kass et al. [8] the active contour method, also called snakes, is widely used to fit a contour on a given image. Above the conventional snake, we add three more functions. First, we interactively move a few points to the corresponding position, and anchor them to keep the structure of points when snakes are involved, which is also useful to get more reliable result when the edge we would like to detect is not very strong. We then use color blending for a special area, so that it can be attracted by a special color [5]. When the color is not very helpful and Sobel operator is not enough to get good edge detection, we use a multiresolution technique [6] to obtain strong edges. It has two main operators, REDUCE with Gaussian operator and EXPAND. The subtraction produces an image resembling the result after Laplacian operators commonly used in the image processing. More times the REDUCE operator is applied stronger are the edges.

4.3. Modifying a Generic Model

3D Points from Two 2D Points We produce 3D points from two 2D points on frames with predefined relation between points from the front view and from the side view. Some points have x, y_f, y_s, z, so we take y_s , y_f or average of y_s and y_f for y coordinate (subscripts s and f mean side and front view). Some others have only x, y_f

and others x, y_s. Using predefined relation from a typical face, we get 3D position (x, y, z).

Dirichlet Free-Form Deformations (DFFD) Distance-related functions have been employed by many researchers [4][7][9] to calculate the displacement of non-feature points related to feature points detected. We propose to use DFFD [11] since it has capacity for non-linear deformations as opposed to generally applied linear interpolation, which gives smooth result for the surface. We apply the DFFD on the points of the generic head. The displacement of non-feature points depends on the distance between control points. Since DFFD applies Voronoi and Delaunay triangulation, some points outside triangles of control points are not modified, the out-box of 27 points can be adjusted locally. Then the orginal shape of eyes and teeth are recovered since modifications may create unexpected deformation for them. Our system also provides a feedback modification of a head between feature detection and a resulted head.



Generic Model 3D Feature lines Modified Head

Fig. 3. A result of DFFD modification comparing with the original head.

4.4. Automatic Texture Mapping

To increase realism, we utilize texture mapping. Texture mapping needs a 2D texture image and coordinate for each point on a 3D head. Since our input is two pictures, texture image generation to combine them to one picture is needed.

Texture Image Generation For smooth texture mapping, we assemble two images from the front and side views to be one. Boundaries of two pictures are detected using boundary color information or using detected feature points for face and hair boundaries. Since the hair shape is simple in a generic model, the boundary of a side view is modified automatically using information of back head profile feature points detected to have nice texture for back part of a neck. Then cylindrical projection of each image is processed. Two projected images are cropped at a certain position (we use eye extremes because eyes are important to keep at a high resolution), so that the range of combined image to make the final assembled image is 360^0. Finally, a

multiresolution spline assembling method is used to produce one image for texture mapping preventing visible boundary for image mosaic.

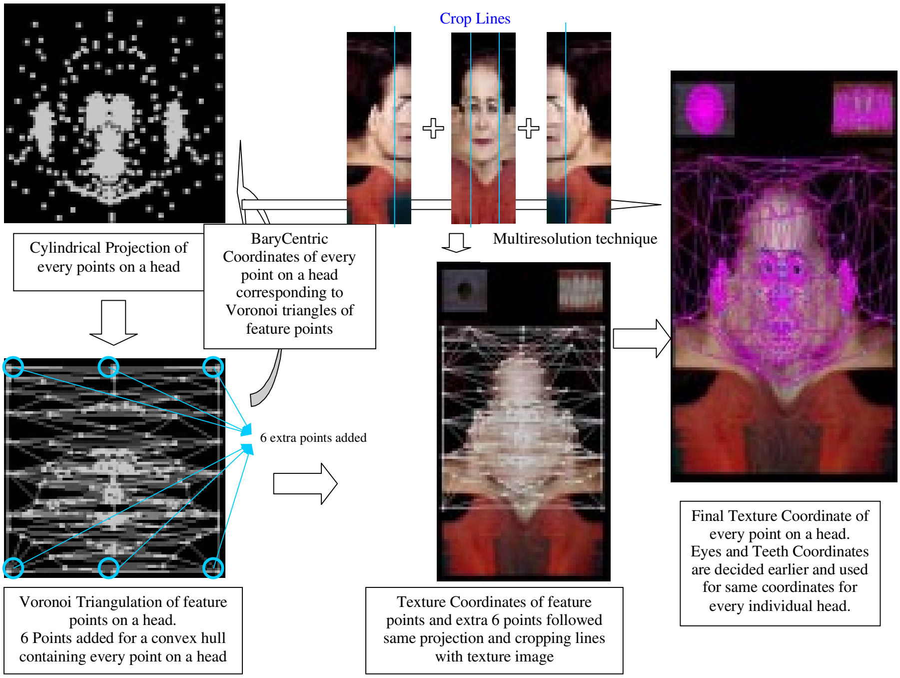


Fig. 4. Texture mapping process.

Texture Fitting The main idea for the texture fitting is to map a 2D image on a 3D shape. Texture coordinates of feature points are calculated using detected position data and function applied for texture image generation. The problem for texture fitting is how to decide texture coordinates of all points on a surface of a head. We first apply a cylindrical projection of every point on a 3D head surface. Extra points are added to make a convex hull containing all points, so that a coordinate of every point is located on an image. Then the Voronoi triangulation on control (feature) points and extra points are processed and the local Barycentric coordinates of every point with a surrounding Voronoi triangle are calculated. Finally the texture coordinates of each point on a 2D-texture image are obtained using texture coordinates of control points and extra points and correspond Barycentric coordinate.

4.5. Result

A final textured head is shown in Fig. 5 with input images, whose process from normalization to texture mapping takes a few minutes.

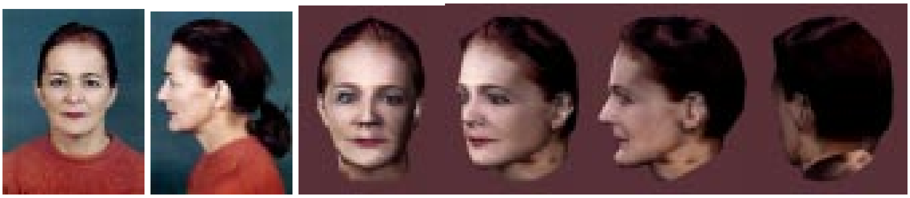


Fig. 5. A final reconstructed head with two input images in left side. The back of head has proper texture too.

5. Talking Head and Animation

In this section, we will describe the steps for animating a 3D face model according to an input speech text, that has been reconstructed as described in the previous section.

Firstly, the input text is being provided to a text-to-speech synthesis system. In this case, we are using the Festival Speech Synthesis System [21] that is being developed at the University of Edinburgh. It produces the audio stream that is subsequently played back in synchronization with the facial animation. The other output that is needed from this system is the temporized phoneme information, which is used for generating the facial animation.

In the facial animation system [22] that is used in our work, the basic motion parameter for animating the face is called Minimum Perceptible Action (MPA). Each MPA describes a corresponding set of visible features such as movement of eyebrows, jaw, or mouth occurring as a result of muscle contractions and pulls.

In order to produce facial animation based on the input speech text, we have defined a visual correlation to each phoneme, which are commonly known as visemes. In other words, each viseme is simply corresponding to a set of MPAs. In Fig. 6, it shows a cloned head model with a few visemes corresponding to the pronunciation of the words indicated.

With the temporized phoneme information, facial animation is then generated by concatenating the visemes. We have limited the set of phonemes to those used in the Oxford English Dictionary. However, it is easy to extend the set of phonemes in order to generate facial animation for languages other than English, as this can be easily done by adding the corresponding visemes.

The facial animation described so far is mainly concerned with the lip movement corresponding to the input speech text. However, this animation will appear artificial without the eyes blinking, and movement of the eyes and head. Therefore, we have also included random eyes blinking and movement of the eyes and head to add more realism into the generated animation. An analysis of the input speech text can also be done to infer the emotional state of the sentence. Then, the corresponding emotional facial expression can also be applied to the animation. For example, the eyebrows can be raised when the emotional state is surprise.

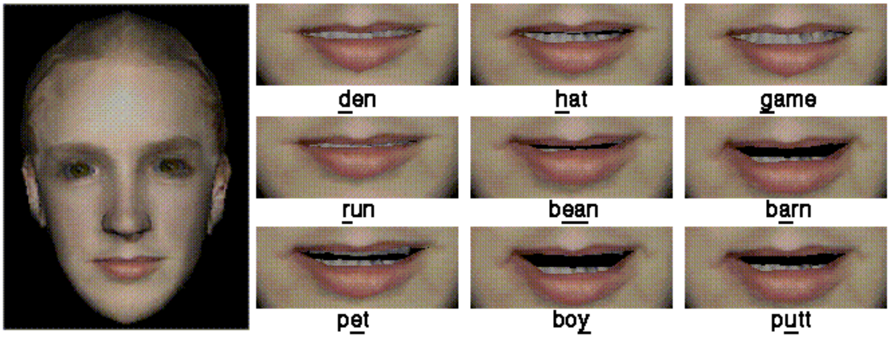


Fig. 6. A cloned head model with some examples of visemes for the indicated words. Our talking head system utilizes 44 visemes and some facial expression parameters.

An example of cloned persons interacting in a shared virtual environment is shown in Fig. 7. Two kinds of generic bodies, female and male, are provided in advance. The generic bodies can be adjusted according to several ratios using Bodylib [28]. We connect individualized heads onto bodies by specifying a transformation matrix. Basically we need four types of data, namely the geometrical shape, animation structure, texture image and texture coordinates. In our case, every individualized head shares the same animation structure. Final rendering is then produced in real time. Our whole process from individualization to final talking head with body in a virtual world takes only few minutes.

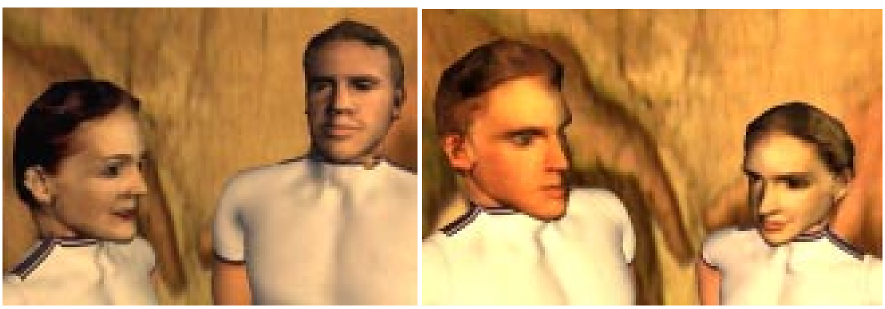


Fig. 7. Cloned persons interacting in shared virtual environments.

6. Conclusion and Future Research

In this paper, we proposed an efficient way of creating the individual face model, in terms of time needed for the creation and transmitting the information to other users, and sending parameters for facial animation. The input of two orthogonal pictures can be easily obtained from any kind of conventional camera. The process of individualization consists of several steps including feature detection on 2D pictures,

Dirichlet Free-Form Deformations for modification of a generic model and automatic texture mapping. The reconstructed heads connected to given bodies are used in a virtual environment. The result is then used immediately to produce an individualized talking head, which is created from given text and viseme database. This whole process can be achieved together with the MPEG-4 framework [27] to create a low bandwidth face-to-face communication between two or more users.

In the television broadcasting industry, the reconstruction method that we have described in this paper will allow actors to be cloned rapidly. Then, the television producer will be able to direct the virtual actors to say the lines and have the appropriate facial expressions in a virtual studio. This will obviously reduce the cost of production.

7. Acknowledgment

We are grateful to Chris Joslin for proof reading this document.

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Animated Impostors for Real-Time Display of Numerous Virtual Humans

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Abstract. Rendering and animating in real-time a multitude of articulated characters presents a real challenge and few hardware systems are up to the task. Up to now little research has been conducted to tackle the issue of real-time rendering of numerous virtual humans. However, due to the growing interest in collaborative virtual environments the demand for numerous realistic avatars is becoming stronger. This paper presents a hardware-independent technique that improves the display rate of animated characters by acting on the sole geometric and rendering information. We first review the acceleration techniques traditionally in use in computer graphics and highlight their suitability to articulated characters. Then we show how impostors can be used to render virtual humans. Finally we introduce a concrete case study that demonstrates the effectiveness of our approach.

1 Introduction

Even though our visual system is not deceived yet when confronted with virtual humans, our acceptance of virtual characters has greatly improved over the past few years. Today's virtual humans faithfully embody real participants in collaborative virtual environments for example and are even capable of conveying emotions through facial animation [1]. Therefore, the demand for realistic real-time virtual humans is becoming stronger. Yet, despite the ever-increasing power of graphics workstations, rendering and animating virtual humans remain a very expensive task. Even a very high-end graphics system can have trouble sustaining a sufficient frame rate when it has to render numerous moving human figures commonly made up of thousands of polygons. While there is little doubt that hardware systems will eventually be fast enough, a few simple yet powerful software techniques can be used to speed up rendering of virtual humans by an order of magnitude.

Because 3D chips were not affordable or did not even exist in the 80s, video game characters, human-like or not, were then represented with 2D sprites. A sprite can be thought of as a block of pixels and a mask. The pixels give the color information of the final 2++D image while the mask corresponds to a binary transparency channel. Using sprites, a human figure could easily be integrated into the decor. As more com-

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puting power was available in the 90s, the video game industry shifted towards 3D. However, the notion of sprites can also be used in the context of 3D rendering. This has been successfully demonstrated with billboards, which are basically 3D sprites, used for rendering very complex objects like trees or plants. In our opinion image-based rendering can also be used in the case of virtual humans by relying on the intrinsic temporal coherence of the animation.

Current graphics systems rarely take advantage of temporal coherence during animation. Yet, changes from frame to frame in a static scene are typically very small, which can obviously be exploited [9]. This still holds true for moving objects such as virtual humans providing that the motion remains slow in comparison with the graphics frame rate. We present in this paper a software approach to accelerated rendering of moving, articulated characters, which could easily be extended to any moving and/or self-deforming object. Our method is based on impostors, a combination of traditional level-of-detail techniques and image-based rendering and relies on the principle of temporal coherence. It does not require special hardware (except texture mapping and Z-buffering capabilities, which are commonplace on high-end workstations nowadays) though fast texture paging and frame buffer texturing is desirable for optimal performance.

The next section gives an overview of the existing schemes that are used to yield significant rendering speedups. Section 3 briefly describes our virtual human model and discusses the limitations of geometry level-of-detail techniques. The notion of dynamically generated impostors is introduced in section 4 with the presentation of an algorithm that generates virtual humans from previous rasterized images. In section 5 the duration of the validity of the image cache is discussed. The following section then shows how this method can be embedded in a large-scale simulation of a human flow. Finally section 7 concludes the paper with a summary of the results we obtained and leads on to some possible future work.

2 Background

There exist various techniques to speed up the rendering of a geometrical scene. They roughly fall into three categories: culling, geometric level-of-detail and image-based rendering which encompasses the concept of image caching. They all have in common the idea of reducing the complexity of the scene while retaining its visual characteristics. Besides, they can often be combined to produce better results, as shown in sections 3 and 4.

Culling algorithms basically discard objects or parts of objects that are not visible in the final rendered image: an object is not sent to the graphics pipeline if it lies outside the viewing frustum (visibility culling) or if it is occluded by other parts of the scene (occlusion culling). Luebke and Georges described an occlusion culling system well suited for highly occluded architectural models that determines potentially visible sets at render-time [3]. One major drawback of occlusion culling algorithms is that they usually require a specific organization of the whole geometry database: the scene is typically divided into smaller units or cells to accelerate the culling

process. Therefore, they perform poorly on individual objects. Because of this restriction it is no use trying to apply occlusion techniques to virtual humans if they are considered individually as we do. Nevertheless, occlusion culling might be contemplated at a higher level if the virtual humans are placed in a densely occluded world, as could be the case when simulating a human crowd for instance.

Geometric level of detail (LOD) attempts to reduce the number of rendered polygons by using several representations of decreasing complexity of an object. At each frame the appropriate model or resolution is selected. Typically the selection criterion is the distance to the viewer although the object motion is also taken into account (motion LOD) in some cases. The major hindrance to using LOD is related to the problem of multi-resolution modeling, that is to say the automatic generation from a 3D object of simpler, coarser 3D representations that bear as strong a resemblance as possible to the original object. Heckbert and Garland [4] presented a survey of mesh simplification techniques. More recently, some more work has been done to provide visually better approximations [5,6]. Apart from the problem of multi-resolution modeling, it is usually quite straightforward to use LODs in virtual reality applications. Funkhouser and Séquin described a benefit heuristic [15] to select the best resolution for each rendered object in the scene. Several factors are taken into account in their heuristic: image-space size so as to diminish the contribution of distant objects, distance to the line of sight because our visual system perceives with less accuracy objects on the periphery, motion because fast moving objects tend to appear blurred in our eyes. In addition, objects can be assigned different priorities since they all may play not an equal role in the simulation. Finally, hysteresis is also taken into consideration in order to avoid the visually distracting effect that occurs when the object keeps switching between two LODs. Recently Pratt et al. [14] have applied geometric LODs to virtual humans in large-scale, networked virtual environments. They used heuristic to determine the viewing distances that should trigger a LOD switch. Each simulated human has four different resolutions ranging from about 500 polygons down to only three polygons. However, their lowest resolutions are probably too coarse to be actually used unless the virtual human is only a few pixels high, in which case another technique than polygon rendering may be considered.

Finally, image caching is based on the principle of temporal coherence during animation. The basic idea is to re-use parts of the frame buffer content over several frames, thus avoiding rendering for each frame the whole scene from scratch [2]. The hardware architecture Talisman [7] exploits this temporal coherence of the frame buffer: independent objects are rendered at different rates into separate image layers which are composited together at video rate to create the displayed image. In addition, the software host is allowed to maintain a priority list for the image layers, which means that objects in the foreground can be updated more frequently than remote objects in the background. Maciel et al. [8] presented a navigation system of large environments, in which they introduced the concept of impostors. An impostor is some extremely simple geometry, usually texture-mapped planes, which retains the visual characteristics of the original 3D object. In their navigation system they replaced clusters of objects with textured planes (i.e. impostors), one of the first attempts at software image-based rendering. But they do not generate the textures on

the fly. Hence their system requires a pre-processing stage during which the scene is parsed: N textures - where N corresponds to the number of potential viewing directions - are generated for every object and stored in memory. This approach is thereby likely to consume rapidly the texture memory. Shaufler and Stürzlinger first introduced the notion of dynamically generated impostors [9]. They managed to solve the problem of texture memory usage since textures are generated on demand in their system. Since then two other software solutions using image-based rendering have been proposed concurrently and independently to accelerate walkthroughs of complex environments [10,11]. Lastly, Sillon et al. used impostors augmented with three-dimensional information for the visualization of urban scenery [18].

Although impostors appear to be one of the most promising techniques their use has mainly been restricted so far to walkthroughs of large environments. We believe however that this technique can bring a substantial improvement to virtual humans too.

3 A Multi-Resolution Virtual Human

In this section we show how a multi-resolution virtual human can successfully be constructed and animated. We have designed a human modeler that solves the traditional multi-resolution problem described above. By relying on implicit surfaces we avoid resorting to complicated algorithms and automatically generate multiple look-alike resolutions of a model. Finally, we explain why a multi-resolution human does not provide a sufficient gain in rendering time.

3.1 Multi-Resolution Modeling

Our real-time virtual human model consists of an invisible skeleton and a skin. The underlying skeleton is a hierarchy of joints that correspond to the real human main joints. Each joint has a set of degrees of freedom, rotation and/or translation, which are constrained to authorized values based on real human mobility capabilities [12]. Unlike other attempts [14] we did not model a multi-resolution skeleton because our purpose was not to demonstrate the effectiveness of animation level-of-detail. Hand joints can be replaced with a single joint though.

The skin of our virtual human is generated by means of an in-house modeler that relies on a multi-layer approach (Fig. 1): ellipsoidal metaballs and ellipsoids are employed to represent the gross shape of bone, muscle and fat tissue [13]. Each primitive is attached to its proximal joint in the underlying human skeleton. The set of primitives then defines an implicit surface that accurately approximates the real human skin. Sampling this implicit surface results in a polygonal mesh, which can be directly used for rendering. This polygonal mesh constitutes the skin of our virtual human model.

Sampling the implicit surface is done as follows: we start by defining contours circling around each limb link of the underlying skeleton. We then cast rays in a star-

shaped manner for each contour, with ray origins sitting on the skeleton link. For each ray, we compute the outermost intersection point with the implicit surface surrounding the link. The intersection is a sample point on the cross-section contour. Once all the sampling is done it is quite straightforward to construct a mesh from the sample points. Thus, we can generate more or less detailed polygonal meshes by simply varying the sample density i.e. the number of sampled contours as well as the number of sampled points per contour. And yet, since the implicit surface remains the same no matter the sampling frequency, the generated meshes look very similar (Fig. 2).

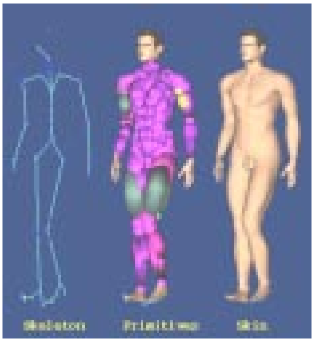


Fig. 1. Multi-layered model [13]

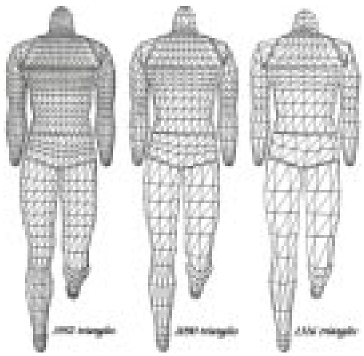


Fig. 2. Body meshes of decreasing complexity

As for the head, hands and feet, we still have to rely on a traditional decimation technique to simplify the original mesh. Manual intervention is still needed at the end of this process to smooth the transition between LODs. The body extremities can cleverly be replaced with simple textured geometry for the lowest resolution (Fig. 3), which dramatically cuts down the number of triangles.

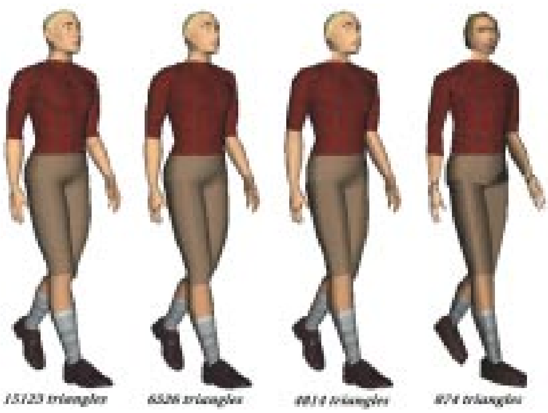


Fig. 3. Levels of detail

3.2 Animation

The skeleton of our virtual human comprises a total of 74 DOFs corresponding to the real human joints plus a few global mobility nodes, which are used to orient and position the virtual human in the world. In the broad lines, animating a virtual human consists in updating this skeleton hierarchy including the global mobility joints at a fixed frame rate. There exist several techniques to feed the joints with new angle/position values. Motion capture for instance is used to record the body joint values for a given lapse of time. The motion can later be played back on demand for any virtual human. Key frame animation is another popular technique in which the animator explicitly specifies the kinematics by supplying key-frame values and lets the computer interpolate the values for the in-between frames.

During animation the appropriate resolution is selected for each individual according to the euclidian distance to the viewpoint. Therefore far objects and those on the periphery contribute less to the final image. Note that we could also take the general motion of the virtual human into account. Finally at a higher level, typically the application layer, virtual humans could be assigned different rendering priorities too. For example, in the context of a human crowd simulation where individuals move and act in clusters the application could decide to privilege some groups.

3.3 Limitations of Geometric LODs

LOD is a very popular technique probably because of its simplicity. It is no wonder that LOD has widely been used in computer graphics, whether in virtual reality applications or in video games. There are some limitations to LOD though. First, shading artifacts may arise when the geometry is extremely simplified. This is conspicuous when Gouraud shading is used because the shading function is evaluated for fewer points, as the geometry is decimated. Popping is another recurrent problem: however look-alike two successive LODs may be, the switch can sometimes be obvious to the viewer. The most widespread solution to this problem relies on a transition zone to smooth the switch. In this special zone both LODs images are blended using a transparency channel. However, this method presents the disadvantage of displaying twice the geometry for a given lapse of time. Lastly, geometric LOD has physical limits in the sense that it is not possible to represent properly a human being with fewer than a few hundred polygons. For example, if we consider textured bounding boxes as the lowest resolution, the number of triangles for our model still amounts to about two hundred in all. Such a representation allows a scene that is made up of dozens of virtual actors to be refreshed at a high frame rate - typically 20 Hz - but to the detriment of the visual quality that drops to a level that is barely acceptable. For all that, LOD remains a very efficient technique that can be used without difficulty in conjunction with impostors.

4 Animated Impostors for Articulated Characters

As first defined by Maciel et al. [8] an impostor is in essence some very simple geometry that manages to fool the viewer. As traditionally the case in the existing literature, what we mean by impostor is a set of transparent polygons onto which we map a meaningful, opaque image. More specifically our impostor corresponding to a virtual human is a simple textured plane that rotates to face continuously the viewer. The image or texture that is mapped onto this plane is merely a “snapshot” of the virtual human. Under these conditions if we take for granted that the picture of the virtual human can be re-used over several frames then we have virtually decreased the polygon complexity of a human character to a single plane (Fig. 4).

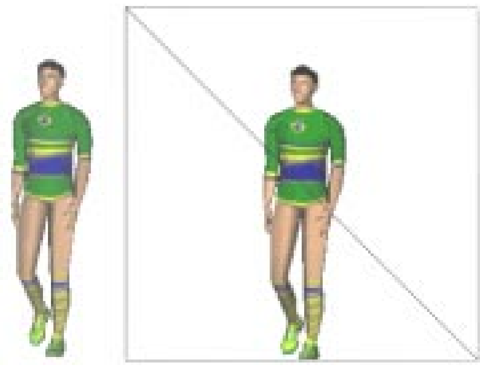


Fig. 4. A Brazilian football player and its impostor

4.1 Impostor Refreshment Approach

The texture that is mapped onto the transparent plane still needs to be refreshed from time to time because of the virtual human’s mobility or camera motion. Whenever the texture needs to be updated a snapshot of the virtual human is taken. This process is done in three steps:

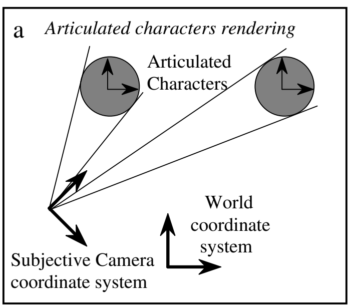
1. Set up an off-screen buffer that will receive the snapshot
2. Place the virtual human in front of the camera in the right posture
3. Render the actor and copy the result into texture memory

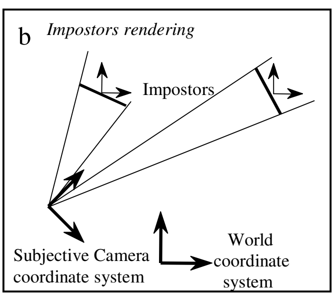
The first stage typically comes down to clearing the buffer. The buffer should be a part of the frame buffer so as to benefit from hardware acceleration. The purpose of the second step is to set up the proper view to take a picture: first, we let the actor strike the right pose depending on joint values. Second, it is moved in front of the camera or alternately, the camera itself is moved. Note that the latter is preferable because the skeleton hierarchy remains unchanged in this case, which may save some

time. In the last stage the virtual human is rendered and the resulting image is copied into texture memory. Once the texture has been generated there only remains to render the textured billboard to have a virtual human on screen. The whole process is hardly any slower than rendering the actual 3D geometry of the virtual human for the following reasons: setting the off-screen buffer up can be done once for all in a preprocessing step. It chiefly consists in adjusting the viewing frustum to the virtual human. Furthermore, this buffer can be re-used to generate several textures of different actors providing that they have approximately the same size. Clearing the buffer is definitely not a costly operation. Letting the virtual human assume the right posture and rendering it would also have to be carried out if the real geometry was used instead. Finally, if the hardware features frame buffer texturing, the frame buffer to texture memory copy is performed within no time. If not, clearing the off-screen buffer and transferring its content still remain all the less costly that the buffer size is small, typically 128 by 128 pixels or less. As a consequence even in the worst cases (very high texture refreshment rates), impostors prove not to be slower than rendering the actual 3D geometry.

4.2 Impostor Viewing and Projection

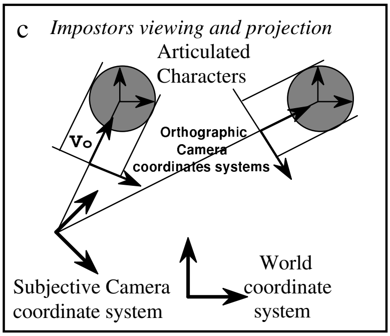
For the sake of clarity, when speaking respectively in the following of texture windows and scene window, we will mean the off-screen buffers where textures of virtual humans are generated and the window where the final, global scene with impostors is rendered.



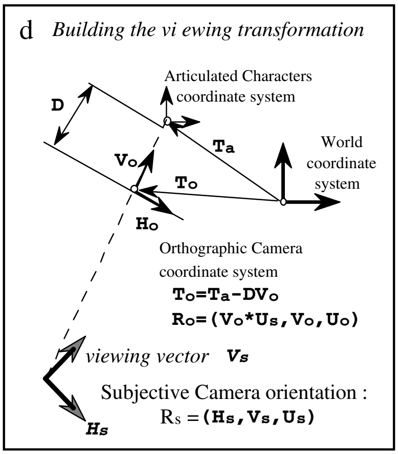


Drawing a. represents a top view of a scene containing two articulated characters. Each character has its own coordinates system. The subjective camera coordinate system defines the user's viewpoint and corresponds to the camera in the scene window. All coordinates systems are expressed with respect to the world.

Drawing b. shows a top view of the same scene rendered with impostors. Each character's geometry is replaced with a single textured plane. Each plane is oriented so that its normal vector points back to the eye i.e. the origin of the subjective camera coordinate system.



Drawing c. explains how the textures mapped onto the planes in *drawing b.* are generated i.e. how snapshots of virtual humans are taken. In the drawing there are two orthographic camera coordinates systems corresponding to the cameras in the texture windows associated with each articulated character. The viewing direction **Vo** of the orthographic camera is determined by the eye's position and a fixed point (later referred to as **Ta**) of the articulated character, as will be explained.



Drawing d. is a more detailed version of the previous drawing. It mainly shows how the orthographic camera coordinate system is constructed. **Vo** is the unit vector derived from **Ta** and the position of the subjective camera. The two other unit vectors that give the orthographic camera's orientation **Ro** are determined as follows: the first vector **Ho** is the cross product of **Vo** and **Us** where **Us** is the normalized up vector of the subjective camera's frame. The cross product of **Ho** and **Vo** then yields **Uo**. Note that this method ensures we obtain a correct frame (**Ho**≠**0**) as long as the field of view is smaller than a half sphere.

Finally, the camera of the texture window (termed orthographic camera so far) must be positioned so that the virtual human is always entirely visible and of a constant global size when we take a snapshot. We proceed in two steps to do so. First, an orthographic projection is used because it incurs no distortion and actual sizes of objects are maintained when they are projected. Second, a fixed point named **Ta** is chosen in the body (it corresponds to the spine base) so that it is always projected onto the middle of the texture window. Practically, **Ta** is determined to be the "middle" point of the virtual human assuming a standing posture in which its arms and hands are fully stretched above its head. Note that this posture is the one in which the virtual human's apparent size is maximal. The orthographic camera is placed at distance D from **Ta** (D is a scalar). During the simulation, the camera is then moved at **To = Ta –** D.**Vo**. Hence **Ta**'s projection necessarily coincides with the center of the texture window. On account of the orthographic projection, D actually does not influence the virtual human's projection size. On the other hand the viewing frustum does. Consequently, it must be carefully chosen so that no parts of the virtual character are culled away. This is done in a pre-processing stage in which the viewing frustum's dimensions (in

the texture window) are set to the maximal size of the virtual human (i.e. with arms raised above its head).

4.3 Several Texture Resolutions

All the work has been realized on Silicon Graphics workstations using the Performer graphics toolkit. Because of hardware/software restrictions concerning textures, texture windows have dimensions that are powers of two. Several texture windows of decreasing size can be associated with every virtual human. As the virtual human moves farther, which leads to smaller image-space size in the scene window, a smaller texture window can be used thus reducing texture memory consumption. Practically, we allocated 256x256, 128x128, 64x64 and 32x32 pixel texture windows for a simulation running at a 1280x1024 resolution. The largest windows were only used for close-up views. As always, it can be a bit difficult to strike the right balance between texture memory consumption and visual realism. In addition to better managing texture memory, using several texture windows of decreasing size also helps to reduce visual artifacts. As a matter of fact large textures of virtual humans that are mapped onto very small (far) planes might shimmer and flash as the impostors move. When several texture resolutions are employed, these artifacts tend to disappear because the appropriate texture resolution is selected according to the impostor image-space size (in pixels). In a certain way this mimics the well-known effect obtained with "mip mapping". Finally, when a texture is generated the appropriate LOD of the geometry can be chosen based on the texture window size.

4.4 Main Current Limitation

Replacing a polygonal model of a virtual human with a single textured plane may introduce visibility problems: depth values of the texels are unlikely to match those of the actual geometry, which may lead to incorrect visibility, as illustrated in figure 5. We did not address this issue in this paper.

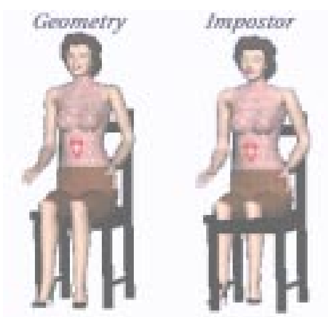


Fig. 5. Incorrect visibility

5 Image Cache Duration

For static objects camera motion is the one and only factor to take into consideration for cache invalidation [9,11]. The algorithm that decides whether a snapshot of a virtual human is stale or not is obviously a bit more complex. However, that algorithm has to execute very quickly because it must be performed for every virtual human at each frame. In our approach we distinguish two main factors: self-deformation of the virtual actor and its global motion with respect to the camera.

5.1. Virtual Humans as Self-Deforming Objects

Virtual humans can be considered as self-deforming objects in the sense they do not keep a static shape, i.e. they can take different postures. The basic idea for a cache invalidation algorithm is that the viewer need not see every posture of the virtual humans to fully understand what action they are performing. A few key postures are often meaningful enough. We propose a simple algorithm that reflects the idea of sub-sampling the motion. The idea is to test distance variations between some pre-selected points in the skeleton. Using this scheme the virtual human is re-rendered if and only if the posture has changed significantly.

Once we have updated the skeleton hierarchy we have direct access to joints' positions in world space. It is therefore quite straightforward to compute distances (or rather squared distances to avoid unnecessary square roots) between some particular joints. In concrete terms we compare four distances (Fig. 6) with those stored when the texture was last generated. As soon as the variation exceeds a certain threshold the texture is to be re-generated. Of course the thresholds depend on the precision the viewer demands. Furthermore, length variations are weighted with the distance to the viewer to decrease the texture refreshment rate as the virtual human moves away from the viewpoint.

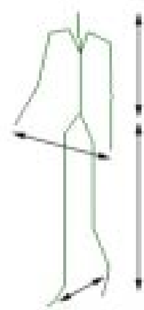


Fig. 6. Posture variations to test

We found out that four tests suffice to reflect any significant change in the virtual human's posture. Nevertheless, other tests should be performed if the simulation is meant to underscore some peculiar actions e.g. grasping of an object requires additional testing of the hand motion. Similarly, it might be necessary to increase or decrease the number of tests when using non-human characters. As a rule the number of limbs gives the number of tests to make.

5.2. Relative Motion of the Actor in the Camera Frame

Instead of testing independently camera motion and actor's orientation we have come up with a simple algorithm that checks both in a single test. The algorithm's main idea stems from the fact that every virtual human is always seen under a certain viewing angle which varies during simulation whether because of camera motion or actor's motion. Yet, there is basically no need to know what factor actually caused the variation.

In practice we test the variation of a "view" matrix, which corresponds to the transformation under which the viewer sees the virtual human. This matrix is plainly the product of the subjective camera matrix (camera in the scene window) and that of the articulated character. The cache invalidation algorithm then runs in pseudo-code as follows:

```
For every virtual human at frame 0  /* Initialization stage */
  Generate texture
  Store View Matrix
End for
For every virtual human at frame N>0   /* Simulation */
  Compute new View Matrix
  Compute View Variation Matrix M (from previously stored
                      view matrix to the newly computed one).
  Compute the amplitude of the corresponding axis/angle
  If angle>threshold
    Generate texture
    Store current View Matrix
  End if
End for
```

Building the axis-angle representation of a rotation matrix **M** consists in finding its equivalent rotation axis as well as the angle to rotate about it [16]. Finally, the threshold that indicates when the texture is to be regenerated can be weighted once again with the euclidian distance from the impostor to the viewer.

6. The Human Flow Test Bed

Our work on impostors originates from earlier research on human crowd simulation that was carried out in our laboratory. However, simulating a human crowd introduces many parameters that alter the frame rate results. We preferred to use a simpler environment in order to assess reliably the gain of impostors on geometry. In our simulation twenty walking virtual humans keep circling. They all move at different yet constant speeds, along more or less long circles (Fig. 7). A fast walking engine handles the motion of the actors, collision between characters are not detected and finally every articulated character always lies in the field of vision so that visibility culling does not play a role.

The first graph shows the influence of the posture variation thresholds used in the texture cache invalidation mechanism. The other factor, that is the viewing angle, was deactivated throughout this test. Along the horizontal axis are noted the posture variation thresholds beyond which a texture is re-generated while the vertical axis shows the amount of time required for rendering the complete scene. The vertical axis is normalized with respect to the amount of time needed to render the whole scene using the real geometry. When the threshold is set to zero every change in the posture triggers a re-computation of the texture, in which case the rendering time logically exceeds the reference rendering time. Note that there is only a marginal difference of 15% though, which clearly shows that impostors are hardly slower than the actual geometry even in the worst cases. Rendering time plummets when the variation threshold is increased: a threshold of 40%, 60% and 80% cuts respectively by two, three and five the rendering time. In practice there is no noticeable difference in the animation of the actors as long as the threshold is smaller than 15%. However, it makes perfect sense to set the threshold to a much higher limit (between 40% and 80%) because the motion remains absolutely understandable. On the other hand it becomes hard to grasp that the actors are walking beyond 90%.

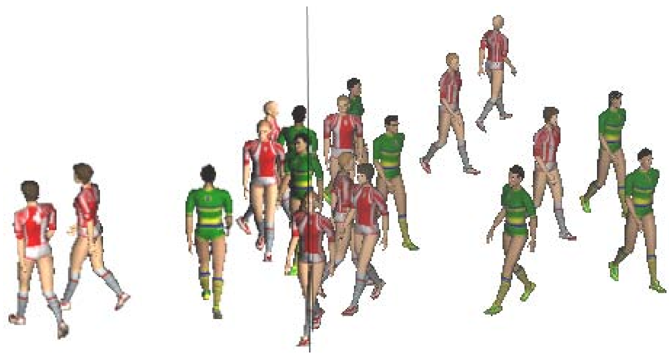
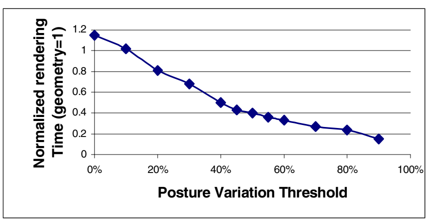
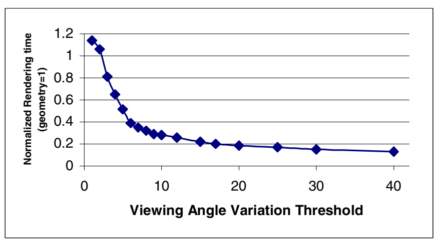


Fig. 7. Simulating two football teams (left: impostors, right: real geometry)



Graph 1.: Rendering speedup as a function of posture variation threshold



Graph 2.: Rendering speedup as a function of the viewing angle variation threshold

The second test focuses on the impact of the viewing angle on the rendering time. Like previously, the vertical axis is normalized with respect to a reference rendering time (that needed to render the whole scene with the actual geometry). On the horizontal axis are marked the viewing angle thresholds in degrees. Similarly to the first test we disabled the other factor in the cache invalidation mechanism. The critical threshold is reached for a viewing angle variation of two degrees only. Viewing angle thresholds of 5, 8 and 17 degrees cut respectively by two, three and five the rendering time. We consider that there is no real degradation of the animation up to 20 degrees. Refreshment of the actors' texture becomes too obvious beyond 30 degrees.

7. Conclusion

This paper shows that image-based rendering can be applied successfully to virtual humans. In particular, we have explained how to generate a texture representing a virtual human and proposed an image cache invalidation algorithm that works for any articulated character and executes reasonably fast. Two major issues, which were beyond the scope of this paper, could be addressed in future work:

1. Our texture refreshment algorithm performs on an individual basis. From the application point of view, the image cache invalidation mechanism should also consider virtual characters as a whole. Above all this would help achieve a quasi-constant frame rate, which is often regarded in virtual reality applications as more important than a high peak frame rate.

2. Because depth information is lost when complex 3D geometry is replaced with an impostor, especially with a plane, visibility may not be correctly resolved. Schaufler recently showed how to correct the visibility by directly modifying the depth value for every texel [17]. However, faster techniques could be investigated in the specific case of virtual humans. For example, the concrete problem depicted in figure 5 could be solved by decomposing the impostor's plane into several planes e.g. one for each major body part.

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Can We Define Virtual Reality? The *MRIC* Model

i i n n l in um

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Abstract. In this paper, we propose a reasoning model aimed at helping to decide on the virtual status of a given situation, from a *human* point of view rather than from a technological one. We first describe how a human and his environment interact. The notion of “reality” will be seen through this description. Then, we propose a set of possible “cognitive deviations” of reality leading to situations of virtual reality. This model provides three major benefits to the field of Virtual Reality: first, a global definition and a systematic mean of categorizing related situations; secondly, the ability to discuss on the virtual status of *real* situations and not only synthetic, computer generated ones; thirdly, a demonstration on how the field of Tele-Operation is heavily related to virtual reality concepts, and some perspectives on future tele-operation intelligent user interfaces.

1 Introduction

ing t on t nt g owt of tivity in t l of i tu l lity it i im po t nt to noti t t 1/ lt oug vi tu l lity y t m ign fo u y um n t nologi l i mu mo v n t n tu i on t ognitiv p t n 2/ t l of i tu l lity l k g n l g m nt on t t m to u n t m ning to giv to t m.

n p opo mo l ll ***MRIC***[1] w i omp i iption of “ lity t of int tion involving um n ing n i nvi onm nt n t of po i l “ ognitiv vi tion llowing l itu tion to om vi tu l. P ovi wit t i mo l w l to i w t u o u itu tion (v n l on) n l l i tu l lity. u t mo t i mo l ow t t t l of l p tion i tu lly vily onn t to i tu l lity n giv u p p tiv on w t oul t futu int llig nt u int f fo t l op tion.

[1] ***MRIC*** is a French acronym for “Model Representing Cognitive x Interaction”

J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 29–41, 1998.

2 Reality as a Set of Cognitive Interactions

2.1 The *MRIC-r* Descriptive Model

u n n n ing u n ing **operator** in ing i i n i n n ny u n n i n i n n

Model Agents

n i u i n in **Mental Agent** n **Physical Agent** n g n n in y i g n i i ing y i i in y i j n i n n n y i g ning n n y i g n in n **Operating agent** n n **External Agent** ing g n n y i u ny u n i n n n i n n i u y i i y ug y n n i y in n i n n n g n i y i n i n g n in **Control Agent** n **Transitional Agent** n g n i n in ig n n i i n n i i n g n n i i i ik fl i n i n n ing n i u n

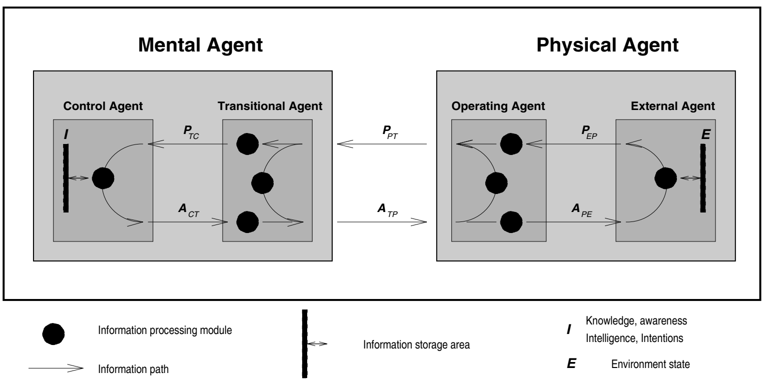

Fig. 1. *MRIC-r* M i y

Information Processing

i i i n in gu i n in i n n A P ing i i i n i n i n n in i i igin n in i n g n g n i in g

v l info m tion p o ing t k m inly vot to t n l ting t output of t p viou g nt into input fo t n xt on . o x mpl

$A_{CT} \rightarrow A_{TP} \rightarrow A_{PE}$ int ntion of w lking i t n l t into qu n of n v impul w i in tu n p o u l o y motion.

$P_{EP} \rightarrow P_{PT} \rightarrow P_{TC}$ lig t mitt y n o j t p o u opti l n v tivity w i in tu n i int p t t “p n of t o j t.

Notion of Interaction

n ition to t o t ig t onn tion t gu 1 ow fou loop k in t info m tion p t

$P_{TC} \rightarrow A_{CT}$ i p nt t op to i ion p o . o in t n t op to n i to g n o j t u t o j t i t m y u n it.

$A_{PE} \rightarrow P_{EP}$ i p nt t tion of t nvi onm nt. o in t n w n g t n im g of ou own o y olli ing wit n o j t p v nt u f om moving t w y w w nt.

$A_{TP} \rightarrow P_{PT}$ i p nt t p op io ptiv f k. o in t n in p n ntly f om t nvi onm nt it lf w know ou o i nt tion in p .

$P_{PT} \rightarrow A_{TP}$ i p nt fl x ( ) tion t t i tion un t k n wit out ny ont ol of will.

MRIC *interaction*

i m n in p ti ul t t g nt in int tion mu t onn t k to ot t oug n info m tion p o ing mo ul . n ou mo l w n v fou kin of int tion t ont ol g nt o t n ition l g nt wit ot t p ting g nt n t xt n l g nt. n int tion t u impli om kin of “ i log tw n t on n g nt in w i t info m tion nt k p n p tly on t info m tion iv . i i w y w o t t t t t p ting g nt int t wit t xt n l g nt. t w oul y t t t y in **mutual action**.

2.2 Notion of Reality

ying to n “ lity i not ou pu po in it woul mo of p ilo op i l m tt . n t w will t t t t lity n n t oug t mo l w ju t i . n ot wo w on i t t t *MRIC-r* mo l i . i point of vi w ing out two impo t nt p t of t notion

Agent classes. g nt in t mo l p i l uty p i int n l it tu n p ti ul t of onn tion wit t ot g nt . f tu n t g nt l .

Agent Instances. o g nt l v l in t n n p ovi wit out lt ing t mo l int g ity. o in t n um n o y n o ot oul two i nt in t n of n p ting g nt.

3 What is Virtual Reality?

3.1 Sources of Virtuality

p opo u l int p t tion of t xp ion “vi tu l lity l ing u to t following nition
i t w on i t t m p t ly. t t m “ lity i to n i in t p viou tion t t i t oug t *MRIC-r* mo l.
lity i t n lity w i look lik t op to ut w i i not tu lly i . i tu li ing lity n m n pl ing o mo ifying on o v l ompon nt of t l itu tion ut till p ving ommon vio . u vi tu li tion p o ll **Type 1 Virtuality Sources**.
n u l pp o w t t t t t xp ion “vi tu l lity nnot plit. om t i point of vi w t vi tu li tion p o no long im t imit ting t l ompon nt of t itu tion ut t t p opo ing to t lly n w on ving i ntly n in p ti ul not t u u l w y. u vi tu li tion p o ll **Type 2 Virtuality Sources**.

3.2 Type 1 Virtuality Sources

Augmented Reality o on int p t tion of t t m ugm nt lity m n mixing l n vi tu l o j t in t m n fo in t n 4 y t m ign to in lu in l tim vi tu l o j t onto liv vi o. pu po i l o to llow p ti ip nt to int t wit t o j t w ll wit t l nvi onm nt. i kin of vi tu li tion p o ompli wit ou nition of t typ 1 vi tu lity ou t ulting itu tion i not x tly t l on ut i n imit tion of l nvi onm nt (t vi tu l o j t oul p f tly w ll l). Mo ov t im ing to llow int tion wit t vi tu l o j t too t ulting nvi onm nt i xp t to v t m w y l nvi onm nt woul . t u t itu tion y ing n w o j t t t v t m w y l o j t woul n p ving ommon vio .

Artificial Reality ti i l lity i oft n f to t ility to t wo l t t o not xi t u t ti ti l wo l n to i pl y t m lik 3 o j t . ollowing t i t minology t two t go i of i tu l lity ppli tion woul 1/ imul ting t l wo l n 2/ ting u t t wo l . i l i tion i not l v nt o ing to ou ognitiv vi ion of t on pt. p nting t t t i om t ing ol t n vi tu l lity t nologi . t i now p mitt wit t t nologi i to n vig t in u wo l . ow v t i kin of vi tu li tion p o f ll into t t go y of typ 1 vi tu lity ou on i t t u vi tu l t ti ti l wo l oul xi t l wo l fo in t n if w uilt p y i l t of u p nting t t ti ti l v lu n put t m tog t in oom. om ognitiv point of vi w ti i l lity tu lly on i t of imit ting p i l of l nvi onm nt. fo w ju t in f ont of not of typ 1 vi tu li tion p o .

3.3 Type 2 Virtuality Sources

Augmented Reality P viou ly w pok of ugm nt lity in t m of ing vi tu l to l n . w on i on p t ing vi tu l to t l n . n nt p p f om N g o n ugm nt lity y t m giv to t op to “ . . . t f ling of t lking to t o j t it lf . . . . n t op to look t ook i not only giv n t in info m tion out t ook ut t ility to t lk i tly to t ook n k it f w mo qu tion . i x mpl of ugm nt lity o pon x tly to w t w ll typ 2 vi tu li tion p o . t nvi onm nt i not ju t imit t ut it vio i mo i . Mo n mo imil p o to u nt y t m .g. in omput i u g y w fo in t n t op to i giv n t ility to t oug t p ti nt kull n in t nk to vi tu l m on t l im g of t op ting on .

Released Reality g n l pu po of ugm nt lity i n m ly to ugm nt o j t iliti p ption info m tion t . imil ly t ount p t of ugm nting iliti i imini ing i iliti . i m n t t not po i ility fo typ 2 vi tu li tion p o li in t ility to “ l l wo l on t int fo in t n t in ility to v tim to p f om l w of p y i t . v l l t i n l y n in om y t m known ugm nt lity y t m . p f t xp ion “ l lity . om x mpl in v l M (i tu l lity Mo ling ngu g) vi w t u n n l / i l olli ion t tion toggl w lk/fly n vig tion mo . o option lik going t oug w ll o flying o t n o pon to l ing v l p y i l on t int . imil ly in v l vi tu l lity vi o g m o vi tu l mu um vi iting y t m t u n jump i tly f om on oom to not l ing t i w y t t mpo l on t int of mov m nt . o p o typ 2 vi tu li tion p o in t l vio i not imit t ut mo i .

3.4 Definition of Virtual Reality

ving om vi tu lity ou in giv n itu tion i n y to p k of vi tu l lity ut not u i nt. u mo l of lity f tu t of g nt on longing to it own l . n ou point of vi w t t m “ lity i nti lly o i t wit t notion of g nt l . i m n t t ll w t vi tu l o not oul follow t mo l t u tu n t u p t t g nt l . imil ly t t m “vi tu l mo to o wit t g nt in t n . woul t n lity t t onfo m wit t ***MRIC*** mo l ut wit vi tu l g nt in t of l on . on i tion l u to p opo t following nition

t u t k itu tion V to x min . i itu tion mu t onfo m wit t ***MRIC*** mo l n will ll itu tion of i tu l lity

if n only if on o mo of it g nt i f om t o pon ing l on ( ) n if ll u g nt (t n ll “vi tu l g nt) n o t in f om l on t nk to vi tu lity ou of typ 1 n /o 2.

in in ny t g nt l qui to t m t topog p y of t onn tion tw n t g nt mu t p v w ll. on qu n t fou typ of int tion i li n y ompon nt of ny i tu l lity y t m. i point of vi w lt oug ou ption of t t m “int tion i p i li i ommonly g on.

4 Immersion and Virtual Reality

mong t ll on pt n i involv in u nt vi tu l lity y t m t notion of “imm ion i t mo t wi ly u . n t i tion w ow ow t on pt of mm ion t wit ou nition of i tu l lity n w mon t t ow ou mo l n l u to i on t vi tu l t tu of l wo l too.

4.1 Immersion and *MRIC*

Overview mo t w ll known of imm ion i t on in w i t op to volv in omput g n t wo l t nk to t uit Mount i pl y (M) t glov . . . n f l p y i lly p nt in t i vi tu l nvi onm nt.

n u itu tion t um n o y n p ting g nt i in ont t wit n w xt n l g nt imit ting t l nvi onm nt. n o to k p o nt p y i l f ling of p n i l imm iv y t m oul on qu ntly i onn t t m nt l g nt f om i l nvi onm nt ut till n l p f t mo l of t um n o y n it “mutu l tion wit t imul t nvi on m nt (p y i l on t int olli ion vi u l o y f k . . .). n f om ***MRIC*** point of vi w t m nt l g nt oul ompl t ly i onn t f om it own p y i l g nt n link to ompl t ly vi tu l on in t . i i l itu tion n mo li own in gu 2. n t i mo l t vi tu l it u tion i o t in y “ vi ting t info m tion p t A_{TP} n P_{PT} tow n imit tion of t l p y i l g nt. i mo li tion ompli wit ou nition of i tu l lity in t w ol p y i l g nt i vi tu l on (it i f om t l on) n t i g nt i o t in t nk to typ 1 vi tu lity ou .

t u p i t t w **not** ugg ting (n w o **not** t ink) t t it oul po i l to p t min f om o y. ut w n y t m p ovi n i nt imm iv f ling to t op to n fo in t n p o u li ti ynt ti im g of t o y t n t op to om lik ly to “ li v t im g ( ) n pt t f k ( ) g t l on . i i w t ou mo l p nt .

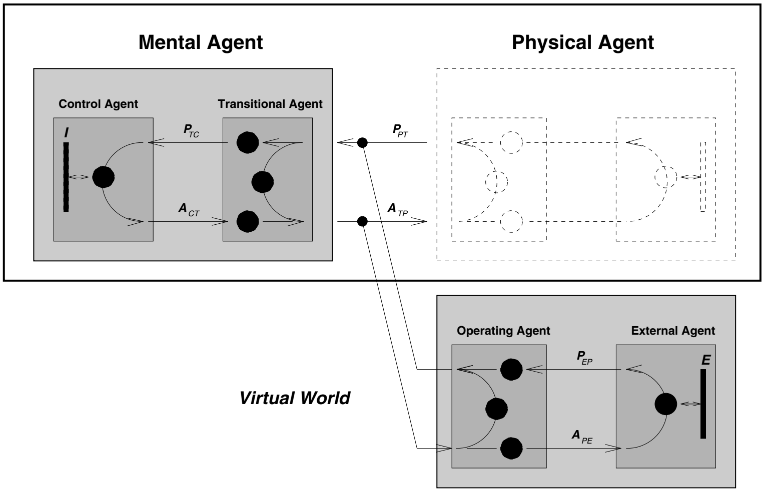

Fig. 2. *MRIC-i* Mo l of mm ion

Limitations t t i tim u nt imm iv y t m f f om ing i l u t y k two impo t nt info m tion p t of t *MRIC-i* mo l n not ompl t ly i onn t t op to f om i own nvi onm nt. n vi tu l o g m t o pl y i in ont t wit t l g oun v n if li v it i t o ou t ut t i itu tion i pt l only long t vi tu l g oun o pon to t l on . n t i itu tion t info m tion p t omp i ing A_{PE} n P_{EP} not ompl t ly vi t qui y ou nition of i tu l lity.

itu tion in w i t p op io ptiv f k i impo t nt in flig t imul tion n ing t t of g vity o l tion i i ult to i v ut oul p nt fo li ti n ing. info m tion loop k A_{TP} P_{PT} (in i t ont ol g nt) i u ntly ok n. i t t ny vi tu l lity y t m oul n l p op ly ll int tion ompon nt in lu ing p op io ption ompli wit t point of vi w of u u .

f t *MRIC* oning mo l i on n w nnot oppo t no logi l gum nt to t o ti l mo l. fo w t ink t t t imul tion y t m it ov o v lop tow vi tu l lity y t m ut y t im p f t u to t nologi l on t int .

4.2 Can Real Worlds be Virtual?

w v only pok n of ynt ti nvi onm nt until now n impo t nt f tu of ou mo l i to giv u t ility to xt n t fl tion to l wo l too. n t n xt p g p w will xpl in w y n ow l wo l n vi tu l un t in i um t n n g in w will po ition t t ition lly m iguou of ugm nt lity.

Real Immersion n t p viou tion w lt wit imm ion in nvi onm nt ("vi tu l imm ion). Now w woul lik to ow t t t p t of t imul tion i not n y to v n imm iv vi tu l lity y t m. on i itu tion of imm ion in ynt ti nvi onm nt w i i im t p o u ing t x t lity. y gui tou in vi tu l mu um w t op to n n vig t in oom (ut till olli wit w ll) n look t t p inting . Now on i itu tion in w i n op to i giv n x tly t m int f (mount i pl y joy ti k . . .) ut i int ting wit l (i t nt) mu um. t i l t t f om t op to point of vi w t itu tion m in t m . l itu tion n ll "vi tu l lity u lik in t imul t w p ovi ompl t ly n w p y i l g nt (l in t of ynt ti t i tim) wit it own ont ol n xt n l g nt . i n w g nt i in vi tu l u non of t tu l p y i l g nt om pon nt uppo to p v . Mo ov in t i vi tu l p y i l g nt i tu lly l on it f ll in t t go y of typ 1 vi tu lity ou . info m tion p t $A_{TP}P_{PT}$ t u vi t t m w y in ot n t mo l p nt in gu 2 i till v li p nt tion of t i itu tion.

i i w y w t ink t t t i tin tion ynt ti / l i not l v nt to l l itu tion "vi tu l lity . ognitiv ly p king i tu l lity mu t not t i t to omput imul tion. i point of vi w i f om t on of u 1 n u u fo w om vi tu l lity y t m mu t on omput g p i fo nyt ing l .

Augmented Reality ugm nt lity itu tion int ting u t y oft n mix l n ynt ti ompon nt . in w ju t w t t l n n un t in i um t n vi tu l lity itu tion t qu tion of t vi tu l t tu of ugm nt lity i . t ink t t t i t tu p n on t itu tion

f t op to in i t ont t wit t l n (u t l op ting i t nt o ot o vi iting i t nt mu um) t itu tion m y tu lly mix of l n ynt ti imm ion o t in t nk to typ 1 vi tu lity ou . n it i pt l to l l t itu tion i tu l lity. t woul tu lly mo pp op i t to p k of **Augmented Virtual Reality** in l imm ion lon i l y itu tion of vi tu l lity w ju t w. f t op to in i t ont t wit t l n n t go l i not to ng t i (lik volving wit t n lu nt gl w i up impo o j t onto t l n) w n no long t lk of imm ion in t op to i xpli itly qui to t y in ont t wit i l nvi onm nt. i f t n o n t omply wit ou nition of i tu l lity. w n p k of ugm nt lity ut not of i tu l lity.

5 Examples

o illu t t fu t ow w n u t ***MRIC*** mo l to i on t "vi tu l lity t tu of u o u itu tion l t u giv t outlin of t oning on two ont i to y x mpl .

5.1 Example 1

n t i x mpl 2 n op to i imm in vi tu l nu l pl nt n i giv n t ility to n vig t in t pl nt n p fo m v l op tion . o pon ing l itu tion i t on in w i t op to t in n imil nu l pl nt. it p t to t ***MRIC-r*** mo l t n w g nt follow

ont ol g nt m in t m in t l itu tion. n t op to till i w t to o n ont ol t vi tu l o y.

it littl t ining (l t ining m n tt y t m) t op to will l to u t joy ti k y fl x to mov oun . i impli t t t t n ition l g nt m in t m in t l itu tion w n t y t m int f i p f tly imil t y t op to . Moving oun in t vi tu l nvi onm nt oul in om o viou w lking in t l oom.

xt n l g nt om t nu l pl nt omput mo l. i i n imit tion of l nvi onm nt. t u in f ont of typ 1 vi tu li tion p o .

p ting g nt om t um n o y omput mo l. lt oug t i mo l i not p f t (.g. only t op to n i vi u lly p nt) t ultim t go l i l ly to imit t t op to o y w i i typ 1 vi tu li tion p o .

now v t min t o pon ing l long wit t n w g nt involv in t itu tion. t u k t v li ity of t g nt o ing t t l p i tion impo y t ***MRIC*** mo l.

op to i giv n ot t ility to mov i vi tu l o y n to p iv it (t l t t n) n p ting t A_{TP} n A_{PT} info m tion p t .

n w p ting g nt t ility to g o j t in t vi tu l pl nt n olli ion t tion i impl m nt n n ling o tly t A_{PE} n A_{EP} info m tion p t .

n v itu tion in w i n w (vi tu l) p y i l g nt i p ovi . i g nt n it int tion wit t m nt l g nt onfo m wit t ***MRIC*** mo l qui m nt . Mo ov t i g nt i o t in t nk to typ 1 vi tu lity ou . t u in f ont of itu tion of vi tu l lity n mo p i ly itu tion of "vi tu l imm ion .

5.2 Example 2

t u t k g in t x mpl p opo y N g o . u wit t n lu nt n w n in li y n tim look t ook t oug t n n v lly int t wit it i tly. t u i l y in l li y

o t i no ot o pon ing l itu tion. y t m o not tu lly p ovi ny n w g nt in t op to i xpli itly qui to t y in i own nvi onm nt. n w n l y on lu t t t i itu tion woul n t ll i tu l lity. u nition p i t t t l t on of t mo l g nt oul pl w i i not t . ow v t i x mpl illu t t t f t t t w n v vi tu lity ou in itu tion wit out it ing i tu l lity itu tion p op ly p king. n giving t "f ling of t lking to t ook it lf on titut typ 2 vi tu lity ou . om t op to point of vi w n o j t (t ook) i vi tu li y mo ifying it no m l vio . i itu tion long to t t go y of ugm nt lity (typ 2) ut o ing to ou nition not to i tu l lity y t m .

6 Virtual Reality and Tele-Operation

n t i tion w mon t t t t t l of t l op tion n vi tu l lity t ongly l t n w ow ow ou mo l n ing out v l int ting p p tiv on w t oul futu int f fo t l op tion y t m ll "t l op tion itu tion in w i n op to i mot ly wo king in i t nt[2] o in i l . u itu tion u ti i l tool to ot t n mit o to t m nipul tion vi (.g. o ot) n iv f k f om it.

6.1 Sources of Virtuality in Tele-Operation

Immersion t i impo t nt to noti t t mo n mo t l op tion y t m u vi tu l lity int f t t p ption l v l. ft u ing n to i pl y t i t nt n t l op to p ovi wit M llowing t m to g t p ti l vi w of t n v n to mov t i point of vi w. n u y t m t i i tu lly to p ovi n imm iv nvi onm nt to t op to . iving t op to t f ling of ing p nt in t i t nt m k u y t m f ll into t t go y of vi tu l lity y t m u t y tu lly impl m nt of l imm ion w i w p ov to of i tu l lity. i on titut t t l tion tw n t l of i tu l lity n l p tion.

Augmented/Released Reality p o of vi tu li ing t l op tion it u tion o not top t t imm ion l v l. M ny nt ppli tion v own t utility of ugm nt lity on pt (u p ovi ing ym oli info m tion up impo on t vi u l l) fo t l op tion . ow v t on pt of ugm nt lity xt n f t t n ju t t p ption l v l t m in i n tw n l op tion n imul t op tion i t t in l t op tion u u lly i v i l . i on t int l to v lop t ining y t m w ll utonomou (n op fully o u t) o ot .

[2] What we call "distance" here means spatial distance as well as temporal distance.

n u ing t ining y t m t t l op to i tu lly giv n n to " v tim in of mi t k . i i f ll into t t go y of l lity n typ 2 vi tu li tion p o .

6.2 Virtualizing the Mental Agent

Until now w v mon t t ow vi tu li tion p o n t t xt n l g nt t op ting g nt n t mo t t w ol p y i l g nt. og i lly t qu tion of t mining w t vi tu li ing t ot g nt in t mo l i n i l i . i qu tion m k n if on i l tiv ly to t l of t l op tion.

Virtual Control Agent y ing utonomou i ion p o in t l op tion y t m w nt n w l of vi tu lity w tu lly p ovi n w (n vi tu l) ont ol g nt in t y t m oll o ting wit t op to . om *MRIC* point of vi w t i i t t tim t t vi tu lity ou lt wit t m nt l g nt it lf. op to tu lly g t t f ling of ont olling not only n op ting g nt ut n op ting ugm nt wit minimum of int llig n t u mo ifying t ommon vio of l op ting g nt . i i of (yp 2) ugm nt i tu l lity not only y p ption not only y tion ut y *fl* .

Virtual Transmutation Until now w on i two m in itu tion m m ion in w i t op to i m nipul ting t nvi onm nt wit " i own n n l p tion in w i t nvi onm nt i mo i in i tly t oug o ot i tiv . n t i l t n impo t nt p o l m i to p ovi y t m y to l n wit t ining p io o t po i l . w p ntly t t long t op to o n t t i tly wit i own o y o wit n i omo p i ynt ti v t lik in n imm iv itu tion p io of pt tion i n y to l to u t int f (joy ti k t glov . . .) wit out ving to t ink out it. wit u on t int t ultim t go l of t l op tion y t m oul to p ovi vi fo w i t woul no mo t ining p io w t op to oul giv o only y moving i own o y. on i m ly o ot y p l of illing n wing op tion . op to i giv n ynt ti vi ion of i m up impo on t im g of t l n . i w y ( ) o n t tu lly noti t p n of o ot ut in t g t t f ling of wo king wit i own n . n illing op tion i n t op to ju t point ng to t illing on n t o ot imm i t ly t k l ill n op t qu t (g ing t ill m y not i pl y in it i not t nti l p t of t op tion). imil ly vi tu lly g ing w n pulling it up to t ol woul m k t o ot l v t ill g w n p fo m t op tion i tly. t i int ting in t i o t ining int f i t t t op to only n to know t n tu l mov m nt n oing ll i lif . n v yt ing o u if t o ot m t op to n w op ting g nt.

i vi tu li tion p o i t u “vi tu l t n mut tion fo t op to . u tituting o ot to t um n o y i typ 2 vi tu li tion p o in t vio of t op ting g nt i ompl t ly ng .

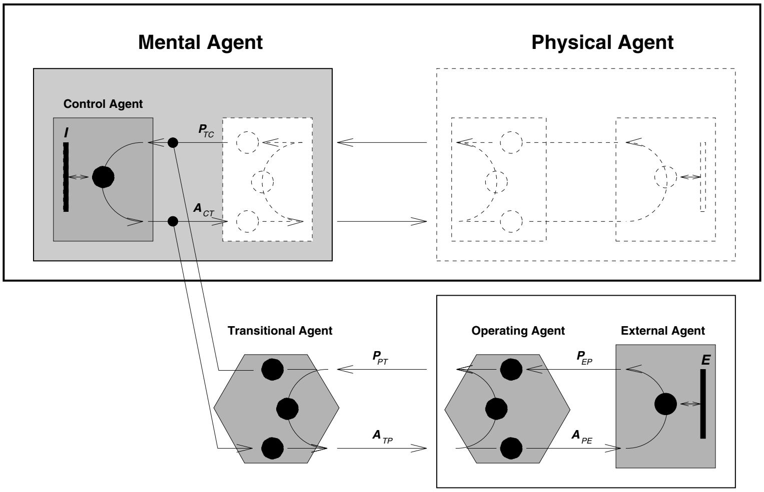

Fig. 3. ***MRIC****-d* nt ntion t tion

Intentions Detection n n v n mo ultim t vi w t i l itu tion i t on in w i t op to o not v to wo k ny mo ! i m n t t if w w nt t op to to k p ont ol ov t v nt t im of t y t m woul to t t f t po i l t op to int ntion n p o utom ti lly. il t v y futu i ti vi w of u itu tion i m nt l ommuni tion tw n t op to n t y t m t i go l n till pp o wit n “int ntion t tion y t m 9 minimi ing t p y i l wo k of t op to . o in t n giv n t p n of n o j t in t nvi onm nt n giv n t t t op to i u ntly moving i m tow t o j t n int ntion of g ing t o j t i oming mo n mo lik ly n oul in tu n t t . n t m of vi tion f om t ***MRIC*** mo l t y t m ommuni t wit t op to t t ig t po i l m nti l v l t t i i tly wit t ont ol g nt. i itu tion i mo li on gu 3 n p nt t ig t l v l of vi tu lity tt in l w il k ping n op to in t itu tion.

7 Conclusion

n t i p p w uilt ognitiv mo l of int tion t oug w i t on pt of lity i n. p opo t notion of “vi tu lity ou im t mo ifying l ompon nt of itu tion in o to m k t m om vi tu l.

notion of i tu l lity w t n n t vi tu li tion of on o mo g nt of t mo l. t ink t t ou vi ion of i tu l lity t m jo n t

u mo l p ovi y t m ti w y of i ing on t vi tu l t tu of ny p ti ul itu tion. i will op fully lp l ifying t notion n it l t on pt .

i t go i tion p o i not limit to ynt ti wo l ut l o xt n to l wo l .

u mo l mon t t to w i xt n t l of l p tion n i tu l lity onn t n p ovi v l int ting p p tiv on futu int llig nt t l op tion int f .

n ou opinion t m in i tin tion tw n i nt i tu l lity itu tion o not li in t ynt ti o l p t of t itu tion ut t in t o p t. il typ 1 vi tu lity ou m inly l t to t notion of imm ion it m t t typ 2 vi tu lity ou woul f mo lpful in t l op tion y t m . ow v t illu t tion it long t i p p t n to ow t t typ 1 vi tu lity ou u ntly mu mo v lop t n typ 2. n in pt on t notion of l p tion i t n 1 m y of om lp to o t t i im l n .

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Distortion in Distributed Virtual Environments

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Abstract. This paper proposes a solution to the problems associated with network latency within distributed virtual environments. It begins by discussing the advantages and disadvantages of synchronous and asynchronous distributed models, in the areas of user and object representation and user-to-user interaction. By introducing a hybrid solution, which utilises the concept of a causal surface, the advantages of both synchronous and asynchronous models are combined. Object distortion is a characteristic feature of the hybrid system, and this is proposed as a solution which facilitates dynamic real-time user collaboration. The final section covers implementation details, with reference to a prototype system available from the Internet.

Keywords: distributed virtual environments, network latency, collaboration, interaction, multi-user, virtual reality.

1 Introduction

Within a distributed virtual environment users interact with objects and state change events are generated. These events are normally transmitted to other users within the virtual environment across a network. The timing of events can be managed using either synchonised or asynchronous clocks.

1.1 No Clock Synchronisation (Asynchronous)

In this model, the environment contains no uniform, global time. Each host has a local clock, and the evolution of each event is described with respect to this local time. Because there is no global time, all event messages are sent without reference to when they occurred, and so events are replayed as soon as a user receives them. In this way, users always perceive remote users as they were some time in the past.

1.2 Global Time (Synchronous).

When using synchronous time, as events are transmitted, they are time-stamped according to a global time that is synchronised between all users [1]. When events are received by a user, they are replayed at the correct global time. This usually requires

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the model to be rolled back to the correct time of the event – time must then be advanced quickly to the current time, to allow real-time local interaction.

1.3 Network Latency

The network connecting users within the virtual environment induces latency of information interchange, which causes problems in the areas of user and object representation. The following two sections and Fig. 1 describe the problems, and suggest that different time management techniques are best for the two areas.

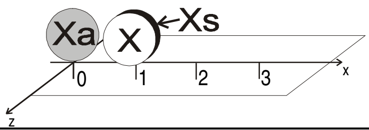
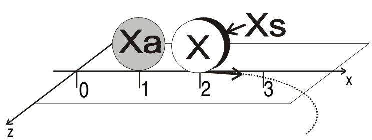
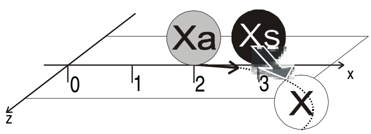
Time	*View seen by remote user*	
t=1		X is moving along a path {z=0,x=t}. Xa (modelled using asynchronous time) is seen delayed by 1 second, Xs (modelled using synchronous time) is consistent with X.
t=2		Local user input causes X to follow a new path (shown by dotted line), this message begins transit to remote user. Xa is delayed by 1 second, Xs begins to become inconsistent with X.
t=3		Message about path change is received by remote user. X still follows new path. Xa still delayed by 1 second, so now the new path can be started without any discontinuity. For the time t=[2,3] Xs is still following linear path, so is inconsistent with X. Now Xs has to discontinuously jump to X.

Fig. 1. User positions as seen by a remote user. X is the local user, Xa is the user modeled asynchronous time, Xs is the user modeled using synchronous time. The network delay, $\overline{\Delta}$, is 1 second

1.4 Asynchronous Time for User Representation

As Fig. 1 shows, user representations will appear discontinuous if a synchronous model is used. The asynchronous model, however, does not lead to discontinuities so is advantageous for user representation.

1.5 Synchronous Time for Object Representation

If asynchronous clocks are used, a local user will always see the past state of remote users and objects, as Fig. 1 shows. The model of objects at the local site will therefore be different to the model at the remote site. If objects appear in different places to different users, the users cannot interact with those objects. The only

solution to this problem is to use synchronised time to model objects, so the positions of objects and the interaction responses will be consistent to all users.

1.7 Proposed Solution

The technique described in this paper proposes a hybrid synchronous/asynchronous model, combining the advantages of each method. A global time must be maintained between all participants to ensure consistency and allow interaction between users and objects. As in an asynchronous model, remote users are displayed at a previous time to ensure no discontinuities arise. The technique employs the causal surface, which facilitates collaborative interaction through the use of object distortion.

2 The Causal Surface

In the 3½-D perception filter [2][3], objects are delayed by different amounts as they move around space.

Asynchronous model for remote users. Remote users are shown delayed by $\overline{\Delta}$ to remove discontinuities, as in an asynchronous model. Objects are delayed by $\overline{\Delta}$ in the local user's view when coincident with the remote user. Therefore, objects that are being interacted with by a remote user are displayed at the same time as that user and the interaction is viewed without discontinuity.

Synchronous model for local user/object interaction. Objects are displayed in real time close to the local user to allow interaction in real-time.

The variable delay is achieved by generating a causal surface function, $\Delta=\boldsymbol{S}(x,y,z)$, that relates delay to spatial position [4]. This surface is smooth and continuous to avoid object position/velocity discontinuities. Fig. 2 shows an example surface, generated using radial basis functions [2].

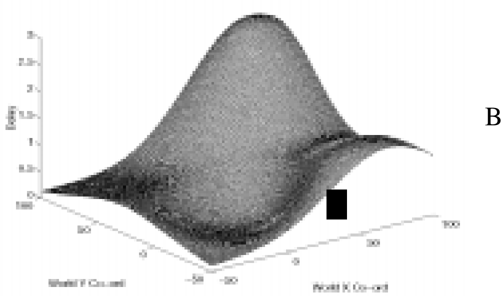


Fig. 2. The causal surface divides space-time into the various causal regions. This figure represents a local user, A, at the position (0,0), and three remote users (the peaks on thesurface). The vertical heights at positions coincident with each user represent the time it takes interactions from the local user to propagate to that remote user. For example, the surface has a value of Δ=1.5 at user B, showing that it takes 1.5 seconds for information to propagate between A and B

In space-time it is impossible for information to reach a point under the causal surface, so the surface represents the bound on the causality of events occurring at the local user. This causality restriction applies to all information in the environment, thereby placing limits on the speeds of both objects and users.

3 Distortion of Objects

3.1 Distortion in the Real World

In the real world, every event takes time to propagate and affect remote objects. Einstein proposed that all physical phenomena was limited by the speed of light. This critical speed limits the propagation of all causal influences, such as changes in gravitational and magnetic forces [5]. Although the speed of light limits all interactions, the nature of some interactions result in an effective critical speed less than the speed of light. Examples of apparent slower critical speeds are the speed of sound, or the speed of wave propagation along a spring. Generally it can be said that all interactions are limited by a critical rate of propagation, although the critical rate may not be constant, and is dependent on the type of signal and on the material being propagated through. Fig. 3 shows how a flexible object results in a critical speed.

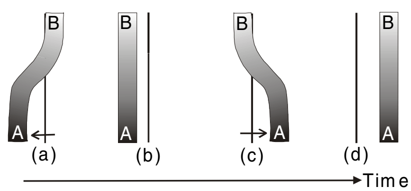


Fig. 3. Distortion of flexible object. Two people, A and B, are holding either end of the object. A is moving the end back and forth at frequency, *f*. When A moves to the left (a), B is initially unaware of that movement. Some time later (b) the wave will reach B and B will be forced to move left. If A now moves to right (c) it will be some time later (d) before B feels this motion

The critical rate can be defined as a propagation time $\overline{\Delta}$ – the time it takes information to propagate through the object. From standard control theory, the propagation time will result in a maximum frequency of interaction, f_R, above which instability occurs, where

$$f_R = 1/(4\overline{\Delta}) \ . \qquad (1)$$

As the frequency of interaction approaches this critical frequency (in the absence of any visual feedback) then each user’s motions will be out of phase leading to resonance making co-operative collaboration impossible. A very good example of resonance occurring can be illustrated if two people try to use a skipping rope *without* viewing the other person (this object has very low stiffness and hence a discernible propagation delay). By looking only at their hands it is possible to initiate a low frequency of rotation but it is impossible for higher frequencies. Brief

experimentation showed that standing waves occurred at multiples of the resonant frequency (an expected result from the control theory [6]).

3.2 Distortion in the Virtual World

The delay associated with propagation of force along objects in the real world is derived from length and stiffness of the material. In the virtual world, however, the delay is derived from the network. The propagation of force as waves of distortion through objects in the real world is therefore analogous to propagation of event messages through the network. By showing the force propagation through objects in the form of distortion, users are made aware of the delay that is present, and can adapt to the maximum achievable rate of interaction.

3.3 Collaborative Interaction

As a user changes the state of objects within their vicinity, those state changes will be reflected immediately on parts of the object close to that user. As the state change messages are transmitted across the network, the state changes initiated by the user will be seen to propagate along the object. When the state changes reach the remote user, the remote users interaction is taken into consideration, and resultant actions are determined [7]. These actions are sent continually as state changes back along the object (and also the network) to reach the local user again. This interaction occurs as a dynamic closed loop feedback system.

4 Implementation

4.1 Object States

Each object in the view seen by a local user will be displayed at a time t-Δ, obtained from the causal surface function $\Delta = \boldsymbol{S}(x,y,z)$. The causal surface is continuous and dynamically changes as users move and as network delays vary, such that the value of the causal surface is always greater than the actual network delay at each user. Given that $\overline{\Delta}$ is bounded within the range [0, max{$\boldsymbol{S}$}], all the states of each virtual object must be defined over the range [t–max{$\boldsymbol{S}$}, t], where t is current time. The trajectory of each object state can be implemented as a function or set of n functions:

$$X(t) = f_i(t) \qquad t_i < t < t_{i+1} \tag{2}$$

for i = 1, 2, ... n, where t_i is the start time of the i^{th} function, and $t_1 \leq (t–\max\{\mathbf{S}\})$. The functions $f_i(t)$ are stored in a temporally ordered list of functions, the most recent function being held at the head of the list. A function $f_i(t)$ can be removed from the list if a function $f_j(t)$ exists in the list such that $t_j < (t\text{-}\max\{\mathbf{S}\})$.

Every defined parameter of each object (the states of the objects) must be specified over the interval [t–max{$\boldsymbol{S}$}, t]. The states of object may include, for

example, position, orientation, colour, temperature, but all types of interaction available to the users must be defined parametrically. A separate list of functions is used for each object state.

4.2 Virtual States

The previous sections have concentrated on distortion of *shape.* Object states define *all* dynamic parameters of the object, including all the states that can be influenced by interaction. Therefore, as each point on the object is delayed by a different amount, *all* dynamic states of the object will change across its surface. For example, if the temperature of an object is increasing over time, a delayed part of the object will be at a lower temperature than a part closer to the (local) heat source.

4.3 Demonstration Program

A simple demonstration program, showing the use of the causal surface is available from the ISRG website. The program allows two users to interact with objects within the same world. A simulated communication channel between the users allows variable network latencies.

5 Conclusion

This paper discusses an alternative solution to prediction for many of the problems associated with network latency within distributed virtual environments. Remote users, and objects close to them are viewed by local users as they were some time in the past, thereby removing state discontinuities, and allowing visualisation of remote interaction. Objects close to local users are displayed in real-time, such that interaction is possible. Objects are delayed by a smoothly varying amount between the local and remote users. Distortion occurs due to the varying delay, and this has strong parallels in the real world – state changes are propagated through objects at a finite rate. In the virtual world, this rate is derived from the network delay, and the distortion allows visualisation of information transfer to allow real-time dynamic interaction.

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VRML Based Behaviour Database Editor

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Abstract. This paper describes a set of models and related data elements that represent physical properties needed by the simulation algorithms in a virtual environment. This paper also describes a VRML based editor called the SimVRML editor. The data elements represent physical properties used by common models that perform general simulation within virtual environments. The data element class definitions described in this paper can be used by model algorithms and model classes related to the following simulation categories: Vehicle operations, ship and submarine operations, aircraft operations, sensor operations (electronic and visual), communications, role playing, combat operations, industrial, chemical and biological. The SimVRML editor is a virtual environment for editing simulation properties used within general virtual environments that support physical behaviors.

Introduction

This paper describes research into data element definitions and model related objects useful for Virtual Reality simulations using the VRML (Virtual Reality Modeling Language) specification. This paper also describes a VRML based user interface for editing static and dynamic state information for VRML based simulation via the Internet or any network in general.

The concept of VRML simulation is commonly referred to as VRML behaviors. The VRML 2 event model, routes and script nodes, in combination with high level programming languages, allows for the use of arbitrary simulation algorithms and models inside of a VRML virtual environment. The high level languages predominantly used for VRML simulation are Java, Javascript, C++ and C.

The VR system for editing and updating simulation static and dynamic state information is the SimVRML editor. The SimVRML editor provides a virtual environment for assigning values to physical properties that are used in VR simulation models and algorithms.

The definitions of the data elements operated on by the SimVRML editor are designed from an object oriented perspective and based upon Java as the VRML

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scripting language. The data element definitions and model objects can be directly mapped to Javascript or C++ data structures.

Previous research on physical properties for distributed network simulation required by general model algorithms has included the DIS (Distributed Interactive Simulation) protocol [1]. VRML research related to DIS is being carried out by the DIS-VRML-JAVA working group associated with the VRML Architecture Group. An alternative to DIS based VRML is the virtual reality transfer protocol [2]. The research presented in this paper is about VRML simulations that are completely generic. It provides an extensible framework for the editing of physically based properties used by multifunctional sets of model algorithms.

Data Definitions for VR Simulation

This research is based upon the following metaphor. Physically based simulations require models and algorithms to implement the simulation. Large numbers of models exist whose algorithms involve physical properties that are well understood, standardized and can be approximated by a Level Of Detail (LOD) paradigm. Such a „simulation LOD" paradigm allows VR simulation models to use approximate algorithms to manage the computational complexity of simulations within a virtual environment. Managing simulation complexity is critical when immersed inside a VRML base virtual environment that includes multi-user behaviors.

Consider the following example of the simulation LOD paradigm applied to a VR/VE or VRML sensor simulation. In the case of a Radar sensor simulation, the coarsest simulation LOD involves the solution of the generic radar equation. The next finer LOD for radar simulation involves a more physically based model of ground clutter, weather and multipath effects. Finer radar model LOD's can be generated by considering more realistic models of system losses, electromagnetic interference, aspect dependant cross sections, antenna directivity, statistical techniques and even hostile actions among role playing fanatics. Descriptions of the equations for various radar model LOD's and their associated model properties can be found in various sources [3 , 4, 5].

These various radar model LOD's require well defined properties that need to be initialized to realistic values and updated as the VE simulation progresses. The SimVRML editor provides a VRML based interface that addresses the need to initialize and update VR/VE physical properties. These properties involve sensor models along with a set of models that provide for the simulation of common behaviors in a VR/VE/VRML universe.

The models that have properties defined for the SimVRML editor described in this paper are models for vehicles, ships, subs and aircraft motion, along with models for communications, sensors, role playing, combat operations, industrial, chemical and

biological. The data element definitions for the properties simulated in the above models are defined as a series of Java classes.

The base class for the SimVRML editor deals with the variables and methods needed to manage data extraction, insertion, descriptive names for the JDBC objects and pointers to default geometries and model algorithms for a set of user defined LOD's. The SimVRML editor has a class that deals with the variables and methods needed to manage data extraction and insertion of dynamic data such as simulation time, pointers to the methods and models used in the simulation, along with status, position, motion parameters and other common simulation housekeeping data.

The SimVRML editor operates on many common Objects that are hierarchical in structure. Such hierarchical objects consist of data elements describing physical properties and also data elements that describe equipment that in turn are described by data elements within other subclasses. Thus, a Vehicle object may have a radio object and an engine object as components of its hierarchical structure.

The SimVRML base class and its subclasses have a public variable that is an enumerated type. The enumeration's are simply ASCII descriptions (less than 33 characters) of the various properties that are shared by the common objects that are simulated via the above models. There are also methods that are used to extract and insert valuations for the properties in the SimVRML base class and its subclasses. Using derived classes and virtual functions and providing an API for the JDBC fields, the SimVRML editor can be made extensible. Thus, a bigger and better model algorithm that needs more sophisticated properties can be „plugged" into the SimVRML editor. Other designers could then just publish their enumerations and „get and put" virtual functions.

Subclasses of the SimVRML base class consist of classes related to physical properties for the following object categories. Hierarchical high level objects like aircraft, ships and submarines, vehicles and people. Low level object categories of the SimVRML editor are sensors, weapons, facilities (Architectural objects), machinery, structural elements of objects, computer hardware and software, chemical and biological. There is also an interaction class that is used by the engagement model and to also keep track of static properties that can be applied to current behavior interactions between objects. The SimVRML base class has common physical properties that are used by all the model algorithms.

Model Related Data / Implementation for VR Simulations

In the SimVRML editor system, the number and sophistication of the properties in the enumeration public variable in the various classes is driven by the sophistication of the model algorithms. The simulation LOD for the SimVRML system is different for the various models.

The sensor models and the SimVRML sensor classes representing the various sensor properties have a highly realistic LOD. The sensor model requires properties related to the advanced radar, active and passive sonar, jamming, electrooptical and lidar equations. The radar model requires properties for the basic radar equation, plus properties related to advance features including electromagnetic interference, ground clutter, antenna configuration, variable cross section, countermeasures and multipath effects. The radar model produces a signal to noise ratio that is generated from a discretization of probability of detection curves versus false alarm rate and number of pulses illuminating the detected object. Physical properties are needed for all the input parameters of the various LOD's of the radar equation. Some radar equation parameters for low level radar calculations lump multiple physical functions into one parameter and approximate the parameters physical value. Realistic radar calculations for high level LOD radar models deaggregate the lumped physical properties for advanced radar model features. These high level radar models require appropriate properties for input into the radar algorithms.

The sonar model requires properties for input into the active and passive sonar equations, sonobuoys, towed arrays and variable depth sonar's [6]. Sonar calculations depend upon the marine environment as much as they depend upon the sonar equipment physical properties. For sonar calculations, the environment is divided into 3 sound propagation zones. Environment effects due to transmission / reverberation loss properties are arrays of values for various ocean conditions and target position relative to the 3 sound propagation zones. The simplest sonar model LOD has table lookup properties for good, fair and bad ocean environments. Sonar classification models require individual target noise properties for subcomponents of an object. Likely subcomponents are machinery (primarily engines and propellers), underwater sensors (especially active and towed) and architectural structures (hull). Target noise properties are required for various speed values. Probability of detection is calculated for individual noise components by dividing the calculated signal to noise ratio by a standard deviation of a normal distribution related to the noise component and then comparing to a normal distribution with mean 1. The primary problem in sonar modeling is generating reasonable physical values for sonar environment and target noise.

The basic Visibility model operates on object detectability properties. Sufficient weather effects are built into the VRML specification for very simple visual calculations. An advanced visibility model based upon electrooptical algorithms [7] requires calculation of the number of sensor pixels encompassing the detected object. Detection probability is generated via an exponential probability distribution that can be discretized into a table look up. The table look up function of the model is based upon optical signal to noise thresholds for the various categories of objects in the virtual environment. If an Infrared or FLIR model is needed then the thresholds require temperature dependence factors.

The Communications model has a moderately realistic LOD. The communications model requires properties related to the basic communications and jamming equations, which are similar to the radar equations without a cross section

factor. Properties related to advanced communications features that depend upon clutter, antenna configuration, interference, multipath and terrain are similar to those properties needed by the radar equations to calculate similar radar effects. The Communications network model has a low LOD to calculate path delays. Path delays are calculated by assuming that delay points behaves according to M/M/1 single server queue with exponentially distributed service rate and interarrival time [8]. Properties needed by the communications network models are mostly dynamic properties related to compatibility of network nodes and communications equipment operational status. Such properties reside in the classes used for simulation housekeeping.

The motion model is a low to medium LOD model that requires properties related to basic ballistics, navigation, navigation error, along with maximum and minimum properties (weight, speed, altitude…). The Flight, ship and submarine operations models are similar to the queuing and probabilistic elements of the communications network model but require interaction with the motion model, fuel consumption properties and specific motion constraints. Fuel consumption algorithms require speed and fuel factors for minimum fuel use and also fuel factors to interpolate fuel use at speeds other than the minimum fuel usage velocity. Ship and submarine operations are similar to aircraft flight operations but with different constraints. Motion constraints can be thought of as a set of rules depending on the type of simulation object and the model applied to the object. Navigation errors are drawn from a normal distribution with mean zero and standard deviation specific to the navigational sensor object. The motion model and all the other models require system failure calculations. For failure calculations, we have equation 1 where A is mean time before failure and B is probability of failure. If B = 0 then the failure time is the current time plus some appropriately large constant.

$$\text{Failure time} = A\,[(\mathrm{Log}(1-\mathrm{rand}(x))/(\mathrm{Log}(1-B))] + \text{current time} \qquad (1)$$

The engagement model is a combat operations model. The engagement model requires properties related to engagement probabilities (failure, detection, acquisition, hit) and equipment characteristics. Air related engagements are based upon simple probabilistic equations. Other properties related to air engagements and air to ground engagements are sensor activation time, sensor scanning arc, lists of target sensors, lists of targets and weapon lifetime. Ground based direct fire engagements are related to a discretization of the Lancaster equations [9] based upon lookup tables. The lookup tables are indexed based upon the characteristics of the objects engaging. Ground engagements between hierarchical objects, such as groups of vehicles are indexed based upon group characteristics. The results of the lookup table searches are passed to a simple probabilistic model. Ground based indirect fire, which is engagement between objects separated farther than a user specified threshold, is modeled via a probabilistic model. Indirect fire assets such as artillery are also included in the direct fire model.

Engagement damage is related to a set of probability factors for failure, deception and repair along with defensive and offensive characteristics. Damage factors are calculated for the following categories of an object: structural, fuel, equipment, and operational status. Damage factors are simple multipliers that are compared to thresholds that enable/disable/ or repair/destroy components of the object.

It is very hard to generate standard properties for people. This is due to the complexity of people and diversity of opinion on how to approximate human behavior. In the SimVRML system, basic person physical properties would be compared to environmental constraints that would be managed by a basic simulation housekeeping process. Beyond constraint checking, such social models would be relegated in the SimVRML system to managing verbal communication within the VR scene and input / output of commands within the VR simulation.

In the SimVRML system, models for structural, chemical, biological processing and any other remaining behavior functions are queuing models augmented by very low level algorithms. These low level algorithms use the current set of properties as thresholds that either disable / enable the object or switch from one geometry LOD to another. As an example, if the melting point is exceeded then the object consisting of a solid geometry would be replaced by an indexed face set of the melted object. Another example would be the failure of an object that would be used by a damage model to affect the state of other objects in the virtual environment.

Model Interaction and Object Interrelationships

In order for the extendable features of the SimVRML editor to function optimally, the interaction of the model algorithms and the object interrelationships need to be defined. The level of complexity of the interrelationships of the object physical properties in an extendable and hierarchical VE generated by SimVRML class schemas is just the local complexity of the data / model interaction. If the virtual environment is distributed or if control is shared in a local virtual environment then several factors influence the complexity of the object / model interactions. The primary factors are time, transfer / acquisition of control, transfer / acquisition of editing rights to the properties and control / acquisition of model algorithms and model LOD's. Time synchronization depends upon agreement on how to broadcast time, when to declare a time stamp valid and how to interpolate time stamps. Much of the preliminary agreement on time is present in the VRML 97 specification [10] as it applies to nodes and simple behaviors.

In a complex VRML simulation one method of agreement about the overall virtual environment within a distributed simulation is to adopt the rules inherent in the DIS specification. The SimVRML editor adopts a hybrid approach consisting of the

DIS rules and methods to override the rules or disallow overriding based upon model / object „rights“. The SimVRML base class has methods to extract data sets from multiple object schemas and to set the structure of the data requirements based upon the model algorithms and model interactions.

The results of the model and data interactions requires that model execution, data storage and data extraction be synchronized. One way to affect global control of various model and physical property interactions is to treat the system as though it was a parallel simulation environment. The housekeeping management scheme chosen for the Virtual Environment generates a set of simulation semaphores. These simulation semaphores are used to make sure that data is extracted or stored at the correct times and that models for the physical behaviors execute in a realistic sequence that produces common sense results.

The SimVRML system is designed to be an extendable system with user defined models and physical properties added to a „base system“ of models and physical properties. In this case there can be multiple simulation semaphore sets that can be activated or deactivated based upon virtual environment rights possessed by controlling avatars or simulation umpires. Suppose you have a VR simulation that has user defined models appended to a base collection of models and their associated physical properties along with their defined interrelationships. If you start with a realistic simulation semaphore set that produces realistic simulation results, how do you produce a realistic simulation semaphore set for the extended VE containing the user defined models. One way to satisfy the requirement that the extended system produce realistic results is to require a sanity check on the results. The simplest form of sanity check would require the simulation state to be outside of obvious error states. Further sanity checks would compare the simulation state for conformation to test parameter limits. Such sanity checks require well defined test simulations within test virtual environments.

Consider the model and physical property interactions for simple linear motion. First, consider scale. Aircraft and ship positions are best stored in geodetic coordinates while ground motion is best served by Cartesian or Universal Transverse Mercator (UTM) coordinates. Motion inside a building is most likely to be Cartesian. Motion over several kilometers is probably best represented by UTM coordinates. Next, consider weather and environmental conditions. Object states are needed for daylight calculations. Navigation properties have to be combined with object motion characteristics. Motion requires awareness of the surrounding objects that exceeds simple collision detection. Motion requires collection of data regarding the visibility status of objects and the properties of the collecting sensors. Thus, data must be extracted from multiple object classes. Motion requires execution synchronization between the motion, navigation and detection algorithms at the minimum. If objects are interacting in a manner that alters the properties and geometry of the interacting objects then interaction algorithms must execute. Results of physical object interactions need to be propagated to the other motion algorithms under the control of motion semaphores.

One solution for the simplification of synchronization of model algorithms is to separate behaviors that must be event driven and simulation cycle based. Cycle based algorithms can be applied to all objects in a simulation subject to pre defined conditions. Processing VR behaviors via a Simulation cycle and then broadcasting the results to the VR objects affected by the behaviors solves some of the problems introduced by object and model interactions. Processing via simulation cycles introduces other problems. One problem is related to a requirement that user actions should be able to trigger model execution asynchronously. Event based algorithm execution requires awareness of all other active and possibly planned events and a set of rules and rights to umpire simulation logjams. Very simple model LOD's can be implemented so that events can be reliably precomputed and queued. Complex model LOD's with significant numbers of property and model interrelationships require constant updating of the event queue.

Consider the detection phase of the motion calculation in the event based portion of the VR simulation. The object in motion would have an instantiation in the VR world along with an instantiation of the detector such as eyes or a night vision goggle. There would also be an instantiation of an object that represents the model that is being executed to process the detection. The methods of the „detection model" object would extract the relevant physical properties from various object classes and spawn events to manage and localize the effects of the interactions between the models and physical properties. Users can make their own constructors / destructors and methods for model objects. Thus the user can attempt to manage the problems posed by model and property interrelationships by incorporating management of the interrelationships in the objects representing the models.

One paradigm for managing the relationships between physical properties and also the simulation model algorithms is to use standard object oriented design (OOD) methodologies such as OMT [11] and Shlaer-Mellor [12]. OMT and other OOD methodologies attempt to generate correct relationships between physical properties, events and simulation model algorithms. By applying OMT or other such OOD methodologies to the SimVRML base classes and simulation model algorithms, a reasonable management scheme for the property / model interrelationships of a baseline SimVRML system can be produced.

By using OMT and other equivalent OOD methodologies, users planning to extend the baseline SimVRML system can minimize effects of their user defined physical properties and models upon the SimVRML baseline system. Similarly, baseline rules for simulation cycle based execution within the SimVRML system can be produced by standard methods of semaphore design. The Shlaer-Mellor Methodology has been analyzed mathematically to examine the question of correctness of OOD for event driven simulations [13].

The SimVRML editor can be used to initialize the state of a Virtual Environment containing realistic general behaviors. This initialization procedure is performed by editing the physical properties that are dynamic. The default VRML description of a virtual environment contains a wealth of geometry, position and VR sensor information. Beyond geometry and standard VRML sensors and interpolators,

what do you put in the housekeeping classes to attempt to produce a simulation semaphore set that provides accepted results under test conditions? The housekeeping properties should include enough simulation state data to keep track of object states used by the models, simulation rights and the defined semaphore sets. In addition to the geometry inherent in VRML nodes, these housekeeping properties keep track of simulation commands and data that can be used to map the model algorithms to the physical properties.

In addition to managing data and model relationships, housekeeping properties are used to store descriptions of multi-user interactions and pointers to static physical properties for interactions. These interactions are different from the model and physical property interactions described above. Multi-user interactions describe behavior effects between objects that are actually engaging in simulated virtual behavior. One of the fundamental multi-user interactions between objects in a virtual environment is information communication. Housekeeping properties are used to track communications text and dynamic data communications within the virtual environment. One function of the Housekeeping properties is to track the simulation state of speech simulations and to track spoken simulation command input. By keeping track of simulation LOD's in the housekeeping properties, the correct set of static physical properties can be extracted by a generic virtual getModel method. By combining low level state information with high level interaction and model LOD state information a virtual environment simulation can truly become more than the sum of its parts.

SimVRML Editor Interface

The SimVRML editor was created using 3D Website Builder [14] and Cosmo Worlds [15]. Although there is still no integrated development environment for VRML behaviors that is affordable, acceptable components are now becoming available. 3D Website Builder is used to create the geometry of the SimVRML editor interface. Cosmo Worlds is used for polygon reduction, VR/VE/VRML sensor creation, VRML routing and scripting within the script node. VRML scripting was done in Javascript [16, 17] and Java [18, 19].

The SimVRML editor interface is a compromise between the goals of a 3D anthropomorphic VR/VE/VRML interface and the cardinal goals of webcentric virtual reality: speed, speed and more speed. A fully anthropomorphic virtual reality behavior editor interface could be realistically composed of 3D subcomponents constructed using thousands of polygons. For example, the average power property used by the sensor model algorithms could have a realistic model of a generator unit with clickable parts in an anthropomorphic version of the editor interface.

The design paradigm applied to the SimVRML editor interface reduces the anthropomorphic aspect of the interface to texture maps. Photo images or rendered images of 3D models representing the various simulation model properties are applied to 3D palettes constructed using simple solid primitives. For properties representing high level hierarchical subcomponents of an object, such as equipment, this texture map strategy works very well and is illustrated in Figure 1.

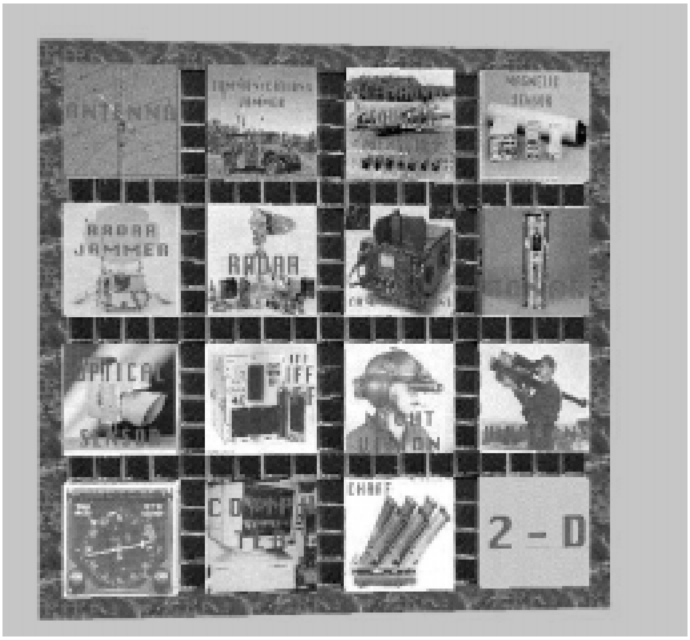

Fig. 1. Equipment Palette SimVRML Interface for Hierarchical Object

For more esoteric and abstract properties with no isomorphism's between anthropomorphism and algorithmic functionally, a different reduction strategy was developed. In the case of abstract properties, an anthropomorphic texture map or maps, representing an aggregate of related properties was generated. Hot spots representing the individual properties of the aggregate texture map are used by the editor to edit property values. Consider the basic radar equation. Sets of texture maps of generic radar properties are placed near to a texture map of a text version of the generic radar equation. The equation texture map is subdivided and overlain upon 3D primitives. Subdivision is necessary to avoid browser environments that do not support the VRML image texture or material nodes transparency features. Since the Virtual Reality Modeling Language is extensible, extending the SimVRML editor interface by users who have added extra model properties is a simple task. Extending

the SimVRML editor interface is primarily a case of image processing and 3D geometry building

User input is through a series of knobs and sliders. This input strategy is made necessary due to the lack of a keyboard sensor in the VRML specification. The 3D Input interface for both sliders and knobs is similar. The interface consists of a VRML model of a slider or knob constructed from primitives and indexed face sets, along with a 3D indicator and a 3D control. 3D indicators are used to display the current value of the property. The user modifies the property values using the movable portions of the slider or knob by clicking or dragging. The user can also use the 3D control to edit property values by clicking on subcomponents of the control, such as arrows. The radar equation texture map palette is illustrated in Figure 2.

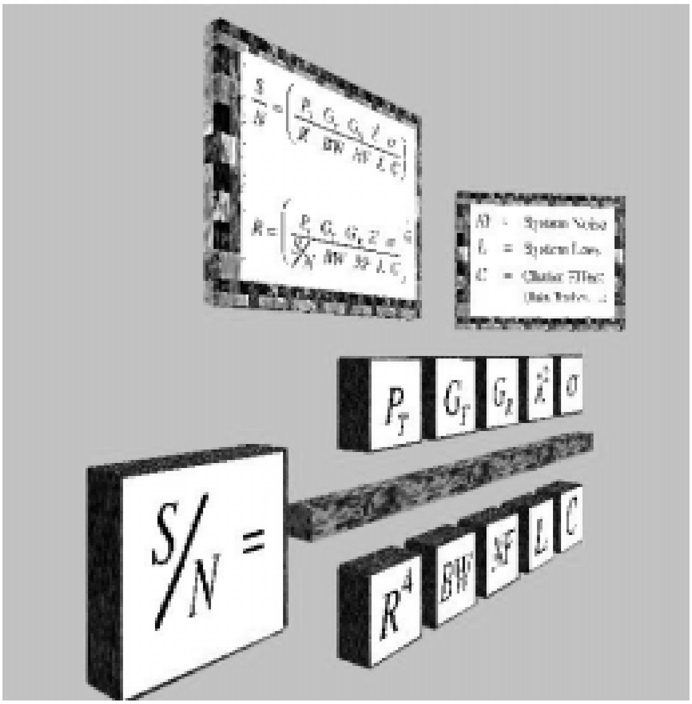

Fig. 2. Aggregate Texture Maps for Radar Parameters in SimVRML Editor

Sliders, knobs, controls and indicators have their own standard set of „SimVRML editor properties". These interface properties are properties for minimum / maximum input values, data type of values, current value, type / size / color of 3D text for display of the current values, scaling factors and position / orientation relative to the slider / knob interface components. Just as the simulation models require a set of standard properties, there is a need for some sort of standard set of input properties

for virtual environments. The geometry of the input widgets is up to the input interface designer. The SimVRML editor interface implements what I consider a minimal set of input properties. Figure 3 illustrates scalar data types. Arrays and other structures could be displayed by duplicating and offsetting VRML group nodes representing the various types of scalar data types displayed via geometry primitives and VRML text.

The SimVRML editor has an option for 2D operation. This option is enabled from within the 3D virtual environment and is based upon Java applets. The 2D option has a SimVRML applet for each of the various object classes. The 3D user input virtual environment is also illustrated in Figure 3

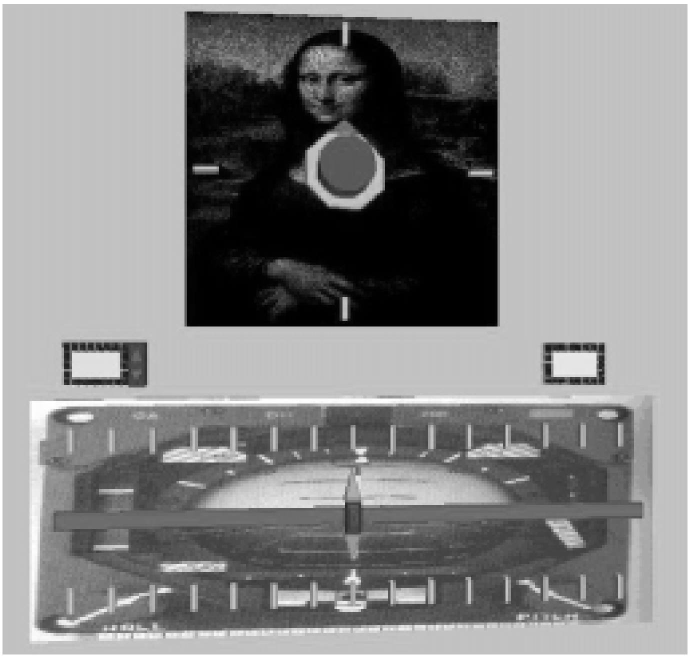

Fig. 3. Slider and Knob Input Interface With Control (arrows) and Indicator

One of the most important considerations related to editing properties for VR simulations is the realism of the data values. The majority of properties in the subclasses of the SimVRML base class have well known published reference sources. Commercial instances of the various abstract objects are particularly well documented. Military and adventure instances of simulation objects are not well documented. Potential sources for such adventure data are user guides for various game simulators, documents published by Jane's Information Group and manufacturers advertising brochures, repair manuals and user's manuals. Many physical properties can be obtained through standard scientific reference works such

as those published by the Chemical Rubber Company. Fascinating and generally correct sources of physical properties are newsletters and publications of hobby organizations such as the American Radio Relay League.

6 Future Work

The SimVRML editor is used to edit static characteristics for physical properties used by VRML behavior models. The next obvious extension is to create a SimVRML layout editor to operate on the variables and methods of the dynamic properties. As an example, consider a Yacht with no engine, antennas, communications or navigation equipment. Using such a layout editor, the user could drag and drop engines, radio and other equipment onto the VRML yacht. The equipment would be from palettes containing thumbnails created by querying the VRML simulation behavior database.

The Model algorithms and the methods for extracting data need for the algorithms have to be implemented through a SimVRML behavior editor. There is also a need for a SimVRML command editor to dynamically input parameters into the VR behaviors. One obvious enhancement to the various model algorithms is to use the fact that a VR/VE/VRML simulation is intrinsically in 3 dimensions. The current damage model simply decides on the fate of a particular VR object. An enhanced damage model could also change the geometry of the object using the createVRMLFromURL method or by inserting and deleting nodes. Physically relevant 3-D dials and indicators would replace two-dimensional textual status boards. In addition a set of OMT diagrams for the baseline SimVRML editor and related models have to be generated.

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The Scan&Track Virtual Environment

u h n hu Kum r mw l[1] n un Ohy [2]

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Abstract. We are developing the *Scan&Track* virtual environment (VE) using multiple cameras. The Scan&Track VE is based upon a new method for 3D position estimation called the *active-space indexing method*. In addition, we have also developed the *geometric-imprints* algorithm for significant points extraction from multiple camera-images. Together, the geometric-imprints algorithm and the active-space indexing method, provide a promising and elegant solution to several inherent challenges facing camera-based virtual environments. Some of these are: (a) correspondence problem across multiple camera images, (b) discriminating multiple participants in virtual environments, (c) avatars (synthetic actors) representing participants, (d) occlusion. We also address a fundamental issue: can virtual environments be powerful enough to understand human-participants.

1 Motivation

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J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 63–80, 1998.

l o t y m n ti o j t pr nt in th urroun in . n ti n or pl on v r l pl on th o y o th hum n p rti ip nt n u or t tin th motion o th p rti ip nt. h motion i th n u to ontrol ynth ti hum n- orm or n v t r o th p rti ip nt. om olution to riv n v t r u in minim l n or r in 11 22 23 .

h r olution n ur y o m r y t m i p n nt upon th iz o th pix l. t i i ult to i r nti t tw n ny two point i th iz o th pix l i l r n th proj tion o oth point ll on th m pix l. om tim ppli tion t rmin th mo o tr kin . i l ppli tion r quir tr k r to mor pr i n ur t . or hum n- nt r ppli tion 18 non- n um rin tr kin m tho r p rti ul rly uit l no wir or t r pl on p rti ip nt .

1.1 Unencumbered Virtual Environments

m r - t hniqu r w ll uit or v lopin un n um rin ppli tion . n xp n iv vi o- m r r l o r ily v il l . hi r i w ll tu i n Kru r work 12 20 21 i w ll known or virtu l nvironm nt in t r tion u in 2 ontour o ilhou tt o hum n p rti ip nt n int rpr tin th m in v ri ty o w y . h n 2 m r -im r u th r i no *depth* in orm tion v il l with th im . u h r r h h n on in th r o omput r vi ion 1 15 16 17 t r o-vi ion 1 19 o j t-r o nition 15 n motion n ly i 16 25 to r ov r th pth in orm tion.

h pro l m o o lu ion i inh r nt in m r - y t m 1 . in 2 - m r im r u to t rmin th p rti ip nt po ition it i i ult to in r wh th r th p rti ip nt h n i hi n hin th ir o y or i in th ir po k t. h o lu ion pro l m i mor v r wh n multipl p rti ip nt r pr nt in m r - virtu l nvironm nt. o th t o our knowl th r r no m r - virtu l nvironm nt wh r th o lu ion pro l m h n u ully olv . olor i rimin tion whi h tr k th h n in olor r not ro u t h ow n li htin h n m k mpiri l l orithm il. noth r m tho to olv th o lu ion pro l m i to on i r pr viou r m to in r th t th h n i *now* in th po k t.

h w ll known orr pon n pro l m i v r-pr nt wh n pur ly vi ion y t m r u . m ntion in 13 th r r v r l omp romi m to r olv th i u o orr pon n n r o nition. v n th n it i i ult to fin topolo i l orr pon n tw n th multipl ontour xtr t rom th multipl m r -im o th m n . n th fi l o omput r vi ion n photo r mm try th r i w lth o r r h on motion tr kin 1 15 16 17 . h r h n mu h r r h ort in th r o un r t n in n r o nition o i l xpr ion o y mov m nt tur n z o th p rti ip nt 20 21 .

h irtu l K uki y t m 26 u th rm l im rom on m r to tim t th p rti ip nt pl n r motion in 3 nvironm nt. Non-pl n r 3 motion i not tr k . n tim t o th joint po ition i o t in in r l-tim y pplyin 2 - i t n tr n orm tion to th rm l im . Oth r point u h

th kn n th l ow r tim t u in n ti l orithm 26 . On xtr t th motion i m pp on to k uki- tor. h y t m tr k pl n r motion o p rti ip nt in r l tim .

lo mo l 2 r u in th fin r y t m v lop t th i L . h y t m u on m r n work with on p rti ip nt in th nvironm nt u in t ti n u h n o . nt r tin ly pth p r p- tion i limit to 2 or x mpl wh n th p rti ip nt jump it i on i r mov kw r . o nti lly th y t m tim t only th 2 in orm tion.

o t o th m r - th ir ju m nt upon th olor in orm - tion n tim t th 3 po ition o th p rti ip nt y u in th in orm tion v il l rom multipl m r . h pro involv olvin th ontourin pro l m orr pon n pro l m n i nifi nt point xtr tion 13 .

m r y t m l o th inh r nt m i uity o 2 - m r proj - tion . hi n illu tr t y rr n in fin r o th t th h ow proj t on th w ll n or x mpl look lik o t. h n multipl m r r u th m i uity pro l m i om wh t r u w h v multipl vi w v il l . ow v r th orr pon n pro l m ro multipl im mu t r olv . xtr tion o only w k y- tur or i nifi nt point rom n im h n inv ti t in r t t il or thi purpo . h i hin i nifi nt point xtr tion i th t m ll oll tion o point m y provi nou h in or- m tion out th int nt or po o th p rti ip nt. r kin th tr j tory o n o j t i th o u o r r h in 25 . n ultipl Li ht i pl y xp rim nt multipl on o li ht r u to n lyz th motion o hum n p rti ip nt 6 . impl li ht i pl y pl on th p rti ip nt r tr k . t i r u th t tw lv point r u i nt to iv n impr ion o tu l motion. hi i int r tin it m y l o provi n n w r to th minim l i nifi nt point on th hum n- o y th t r u i nt to un r t n th motion o th p rti ip nt.

v ri ty o ontour- xtr tion m tho h v n v lop or tur un r t n in 27 . h mm r iv -vi o 29 ppli tion u olor v r in o multipl m r -im to t rmin th olor o 3 ri -point . n k 28 u minimiz tion n plin - ontourin to lo k onto n o j t o int r t in th im .

ntly th r h l o n rowin int r t in u in u ul 2 n 3 t tru tur or r ov rin th pth in orm tion. in t. l. 29 om in th vi ion n r phi t hniqu or pro in th vi o- tr m offlin non- int r tiv ly o th t multipl p rti ip nt n vi w th pro n rom i r nt n l t r pr pro in h n ompl t . n imm r iv vi o th olor- i rimin tion i u tw n r m to i nti y pix l o int r t whi h r th n proj t to fin th vox l in 3 - ri p on th olor o th r ion (pix l) o int r t. h m r hin u l orithm i th n u to on tru t th i o- ur o int r t 29 . hi m tho o not tr k th p rti ip nt int r tiv ly in virtu l nvironm nt. n t it pro th vi o- qu n rom multipl m r n llow p rti ip nt to vi w th pro t .

2 The Scan&Track System

r v lopin th n r k virtu l nvironm nt u in th om tri - imprint l orithm n tiv - p in xin m tho . h om tri imprint l orithm i upon th ppro h th t n -point o th ylin ri l o y- p rt r mo t lik ly to vi i l ro multipl m r n th r or r mor lik ly to i ntifi u in th ontour o th im . h m in i r- n tw n th propo n r k y t m n oth r xi tin m r - virtu l nvironm nt i th t ( ) olor i not th m in o u or i nti yin i nifi- nt point on th p rti ip nt o y in th n r k n ( ) i nifi nt point h n with th po in th om tri -imprint l orithm n th r or m y i r nt p n in upon th po . n h r m w k wh r r th tip o th ylin ri l 2 - h p in th m r -im . o th om tri -imprint ppro h i un m nt lly i r nt th n th vi ion y t m wh r th m i nifi nt point r ou ht in v ry r m . m jor v nt o th tiv - p in xin m tho i th t po ition tim tion r provi *without* ny knowl o m r -ori nt tion. x t m r ori nt tion i riti l or oth r xi tin m r - y t m to- t 29 .

h tiv p in xin m tho i nov l m tho or tim tin th 3 po ition u in multipl m r -im . urin pr pro in th y t m u thr m r to r or pl n r- li ont inin impl p tt rn rr n on r ul r ri . h pl n r li i th n mov t r ul r int rv l n th orr - pon in m r -im r tor . n thi m nn r *active-space* or th 3 - p tw n th p r ll l li i nn . urin pr pro in th nn m- r im r pro to r t n tiv - p in xin m h ni m whi h m p 3 point in th tiv - p to th orr pon in proj tion on th m r -im .

On th tiv - p in xin m h ni m h n r t th lo tion o 3 point n tim t y u in th point proj tion on multipl m r -im . h tiv - p in xin m tho i l l th *same* 3 - p oul nn or oth th low n th hi h- n y t m . in th iz o th 3 tiv - p n l o v ry th 3 tiv - p workin volum it l i l l . n omp ri on to oth r tr kin m tho th tiv - p in xin m tho voi th ompli t m r li r tion op r tion . th tiv - p in xin m tho provi 3 p -lin rity or po ition tim tion th i tortion u to m r proj tion r utom ti lly voi .

n th ollowin tion w xpl in oth th om tri -imprint l orithm n th tiv - p in xin m tho .

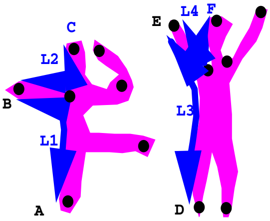
3 The Geometric-Imprints Algorithm and Associated Results

o y po tur xpr motion n r v l our inn r- l . or x mpl th ontour- r win in i ur 1 oul int rpr t n po . imil rly

i ur 1 oul m n th t th p r on h ju t n vi toriou . h h r t ri - ti o oth th po n ptur y om k y-point on th ontour hown in i ur 2. Our om tri -imprint m tho i on th o rv tion th t hum n o y p rt r mo tly ylin ri l in n tur p i lly tho whi h r th i o rti ul t motion. h n w look t p rti ip nt rom multipl m r -im th *tip* o th ylin ri l o y- h p i xp t to vi i l rom m ny m r . h tip-point fin th *geometric-imprint* o ontour in th n r k y t m. h om tri -imprint m tho xtr t in orm - tion out th ylin ri l h p rom ontour. n o i ur 1 fin r tip r th lo i l n in o th ylin ri l hum n rm n th n t th l ow i quit o viou n houl t t . imil rly w h v hown om point in i ur 1 to in i t th om tri urv n in n th lo i l- n o ylin ri l o y p rt .

wi h to ptur th point o th ylin ri l n in o 2 ontour rom th hum n- ilhou tt hown in i ur 3 - . om oth r point m y in lu p n in upon th urv tur o iv n ontour. on i r thi t o point th *geometric-imprint* o th im . hi i u th point n th ir topolo y ilit t t rmin tion o th po o th p rti ip nt. Our motiv tion or v lopin th om tri -imprint m tho w to l o r u th ompl xity o th orr pon n pro l m. on i r 2 - ontour xtr t rom multipl m r -im lookin t ylin ri l o j t (i ur 2). h tip o th ylin ri l o j t woul proj t tip o 2 - ylin ri l urv in mo t o th 2 - ontour . t i mu h i r to orr pon xtr miti o urv ro multipl m r im 38 . om tri -imprint r p n nt prim rily upon th n l- y i o ontour o n im thu our ppro h i i r nt th n oth r xi tin m tho wh r m k y- tur o th im in v ry r m mu t tim t . or x mpl in m ny ppro h w ll our rli r ort 26 th m joint r tim t in v ry r m . hi i rt inly u ul wh n th i pl y pro r m i k l ton- n th joint in orm tion i n or pl in yn- th ti hum n- tor in ir po . n th om tri -imprint l orithm wh n th p rti ip nt um i r nt po ition th h p o p rti ip nt ilhou tt on th m r -im l o h n . h r or w xp t th om tri -imprint t to v ry rom on r m to noth r p n in upon th h p o th urv in th m r -im rom on mom nt to noth r.

h v impl m nt n *automatic* r ur iv plittin l orithm whi h n u ully l with r itr ry (multipl ol in) urv . i ur 3 how th xp t orr pon n tw n om tri -imprint o on po to noth r. i - ur how thr m r -im (-) o th m po n th ir om tri - imprint . or t il o thi l orithm r in 39 .



(a) Dancing (b) Elation

Figure 1: Postures express emotions

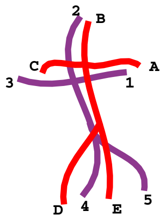
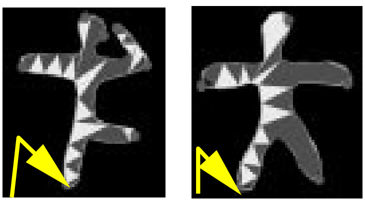


Figure 2: The Correspondence Problem



(a) starting point (b) starting point

Figure 3: (a) Spread out pose.Five geometric imprints. (b) Dancing pose. Seven geometric imprints.

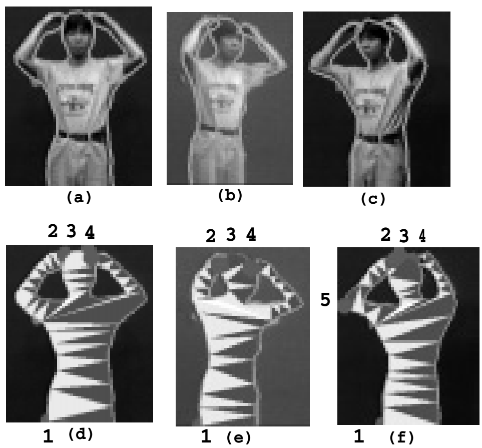


Figure 4: Geometric-imprint points of three camera images for the same pose. (a-c) three camera-images for the same pose, (d) 4 (e) 4 and (f) 5 geometric-imprint points.

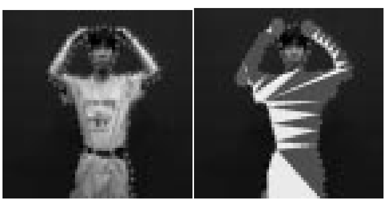


Figure 5: (a) Scan-line algorithm for automatic extraction of the contour. (b)Geometric-imprints algorithm using the automatically extracted contour

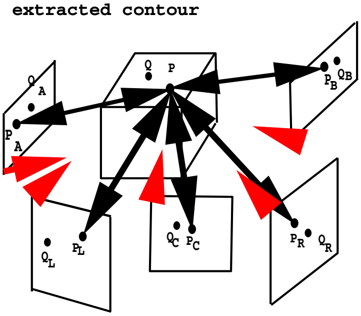


Figure 6: The relationship of points P and Q changes depending upon the view as the cameras move around them.

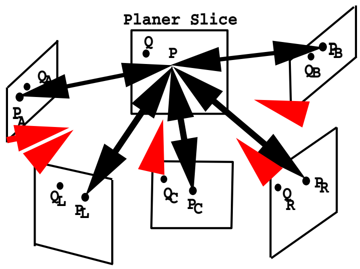


Figure 7: The relationship of the point on a slice remains same for a variety of planar views in the same hemisphere w.r.t. to the slice.

Only on houl r point in i ur h n i ntifi th om tri - point. h impl m nt tion i ntifi fiv ylin ri l n -point on thi ompl x urv in i ur n . n i ur w h v u th m po or th im ptur rom thr m r . Noti th t ll th i nifi nt point m rk on to fiv in i ur - r ommon in th thr fi ur . On xtr l ow-point i l o om tri -imprint point in i ur . n our impl m nt tion w h v m inly hown th tip o ylin ri l h p how v r th pl wh r ol in o ur n l o th om tri -imprint point xpl in in 39 . hown in i ur imil r topolo i l urv n r t imil r om tri imprint t. On th om tri imprint h n o t in it i mu h i r to fin orr pon n . Not th t om tri -imprint point m rk 1 in i ur - orr pon to th m 3 -point (ri ht-hip). imil rly point m rk 2 3 orr pon to th tip o th ri ht h n h po ition n th tip o th l t h n r p tiv ly. Not th t th ixth point n i r y u in th tiv - p in xin m tho xpl in low. h im -imprint o th ixth point in i ur m t h with ny im -point in th oth r two m r -im will r ult in no 3 point orr pon n u in th tiv - p in xin m tho . hu th orr pon n pro l m in th n r k y t m i implifi . i ur 5 how om tri -imprint o t in y u in n *automatic* n-lin l orithm 0 . olor im r t `http://www.cs.uccs.edu/~semwal/VW98`.

4 The Active-Space Indexing Method and Associated Results

4.1 Camera Calibration, Space-Linearity and Over-Constrained Systems

h r h v n m ny tt mpt to tim t th 3 motion o th p rti ip nt with minim l num r o point u or m r - li r tion or x mpl thr point r u i nt u t y llm n 6 . ntly th r h v n m ny tu i wh r fiv or mor point r u or t r o-m t hin n r tin nov l vi w 20 21 . o t o th y t m whi h u minim l num r o point r u u lly un r- on tr in in th n th t ny rror in m r - li r tion or m r ori nt tion tim t m y r ult in v r r i tr tion n ur y rror 13 .

n impl m ntin th tiv - p in xin m tho w u v r l point urin pr pro in n r t p ti l 3 - t tru tur u in th point . Our motiv tion to u v r l point i to u ivi th tiv - p o th t only w point r u lo lly to tim t th po ition urin tr kin imil r to th pi -wi i n or ur n ontour . n y t m u in minim l num r o point lo l li r tion i u n th r or it r t n un r- on tr in y t m 13 . h non-lin rity n tr kin rror r mor pro oun u to th u o n un r- on tr in y t m.

n our ppro h y u ivi in th 3 tiv - p into m ll i joint vox l or 3 - ll w u only m ll num r o point whi h r th v rti

o th 3 -vox l or tim tin 3 po ition in i th t vox l. n thi w y only w point tim t th 3 po ition. h m jor v nt o u in l r num r o point i th t th non-lin rity u to m r li r tion i r u . n p rti ul r w n um th t lin r motion in i th m ll 3 -vox l p will l o proj t lin rly on m r -im . hu th t o m r - i tortion r voi . or ur t tim tion within th 3 - ll or vox l r po i l thi umption l o llow th u o lin r int rpol tion within th 3 - ll or vox l.

4.2 Estimating Depth Using Multiple Cameras and Slices

on i r th proj tion o two point n in i ur 6. p n in upon th vi wpoint n multipl m r in th two point n th proj tion o th two point h n p rti ul rly th ir r l tion hip h n w mov rom l t to ri ht rom im pl n to im pl n vi pl n L (L t) (nt r) n (ri ht) hown in i ur 6. h p ti l in orm tion tw n th two point i lo t. ow n w in r th t point Q_A n Q_B r tu lly th m point in 3 p N xt on i r two point n on pl n r- li n th m t o multipl m r hown in i ur 7. Not th t th p ti l r l tion hip o proj tion o point n in ll th pl n in th m h mi ph r w.r.t. th pl n r li r m in m . hu it i mu h i r to l with point in pl n r- li . n ition zoom-in or zoom-out l o o not h n th r l tion hip o th vi i l point . n p rti ul r w.r.t. to two lin L1 n L2 on pl n r itr ry zoomin o th m r or h n in th ori nt tion o th m r in th m h mi ph r hown in i ur 8 o not h v n t on thi r l tion hip. n p rti ul r point r m in to th ri ht o proj t -lin L1 n point to th l t in oth th proj t -im . oth point r ov th proj t -lin L2 xp t . n now xt n th i to m ny lin . ri o lin p rtition th li into v r l i joint ri - ll in i ur 9. i ur 9 l o how m r im whi h i in pl n r li t n n l pointin li htly upw r . h r i p r p tiv orm tion o th lin y t th r l tion hip o point n i on i t nt with th pl n r li n th 2 ll-in x o oth point i m .

ll thr m r r pl in u h w y th t th y r in th m h mi- ph r w.r.t. th tiv - p li . L t 1 2 n 3 th proj tion o 3 point on th l t nt r n ri ht m r im r p tiv ly. hi i hown in i ur 9. ll th tripl t (1 2 3) n imprint- t or point . r 1 2 n 3 r th 2 pix l oor in t o th proj tion o point on th l t nt r n ri ht m r -im r p tiv ly. 3 point i vi i- l rom multipl m r th n th lo tion o th imprint o th 3 point in multipl m r -im n u to tim t th 3 po ition o . iv n th im -imprint (1 2 3) th *active-space indexing method* fin th 3 - ll or vox l ont inin th point . n our pr nt impl m nt tion th tripl t r provi y th u r.

4.3 Preprocessing to Create Active-Space Indexing

ultipl pl n r li n now t k or tim tin th pth in orm tion. h tiv - p li o upy p ll n tiv - p volum or imply n *active-space*. h li ivi th tiv - p into t o i joint 3 - ll or vox l . m r -im or v ry li r pro on y on . urin pr pro in on m r i pl u h th t th vi w-norm l i p rp n i ul r to th whit - o r u or our xp rim nt . h oth r two m r r to th l t n ri ht o th fir t m r hown in i ur 9. h v ho n 12 y 12 ri p tt rn wh r ri int r tion r hi hli ht y m ll l k ir l . h ri -p tt rn o upi 55 m y 55 m p on whit - o r . h qu r o th ri i 5 m y 5 m. h whit - o r i phy i lly mov n r or y thr m r t th m tim . i ht u h r or in r ult in i ht li or v ry m r . h int r- li p in i 10 m. h whit - o r n th ri -p tt rn on it r vi i l rom ll th thr m r . h tiv - p volum i u o 55 m y 55 m y 70 m. h tiv - p i l r nou h to tr k th n upp r o y o th p rti ip nt or two t o xp rim nt w h v on u t o r. l r r tiv - p n ily on tru t y u in l r r p n l in t o th m ll r whit - o r u or our xp rim nt . ll th 12 y 12 ot on i ht o th li r hown in i ur 11 - or ll th thr m r . u o th p limit tion w o not xpl in th pr pro in l orithm h r . or t il pl r r to 38 .

4.4 Position Estimation

o tim t th lo tion o 3 point iv n it imprint- t (1 2 3) w h v impl m nt th ollowin l orithm. h tiv - p in xin m h ni m fin th 3 lo tion on th imprint t tripl t. h tripl t in our impl m n- t tion i provi y th u r y u in mou -pi k on th r p tiv m r - im . or x mpl i th tip o th no i vi i l in ll th thr m r im or our xp rim nt th n w n li k on th tip o th no in ll th thr im to o t in tripl t (1 2 3) or th no . hi i hown in i ur 10 - wh r 1 2 n 3 r th proj tion on th l t nt r n ri ht m r or th point .

iv n im -imprint (1 2 3) orr pon in to 3 -point w r h ll th i ht li n fin th vox l ont inin point . u to p limit tion w h v not xpl in th t il o thi l orithm h r . t il r in 38 .

i ur 10 - how th r ult o our impl m nt tion u in ix imprint- t . orr pon in 3 vox l r l o hown y vi u lizin th m onn t k l ton fi ur . h v hi hli ht th orr pon in point in th im in i ur 10 n 10 . noth r li htly i r nt t o point i hown in i ur 10 . i ur 10 how th p rti ip nt po y u in n in-hou ynth ti - tor v lop in our l or tory. h v l o t t our tiv - p in xin m tho y u in two i r nt m r ttin thu r tin i r nt t o li n in xin m h ni m n h v o t in imil r r ult .

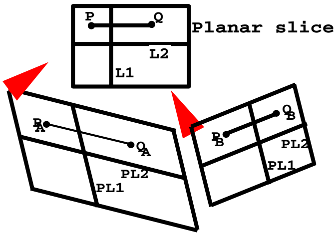


Figure 8: Projection of two points on two planes.

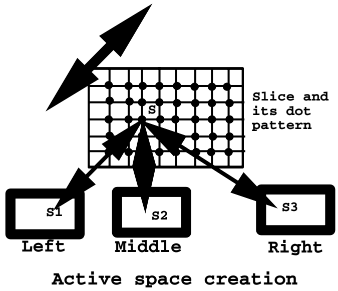


Figure 9: Imprint-set (S1,S2,S3) for point S. S1, S2, and S3 are 2D points on the respective camera-images.

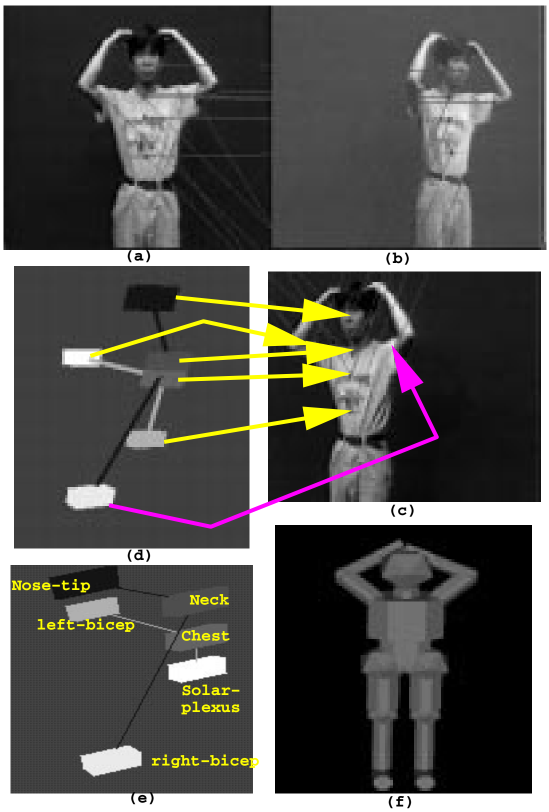
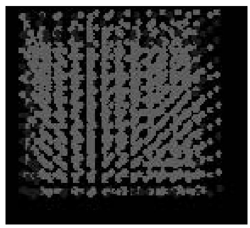
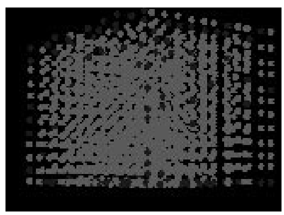


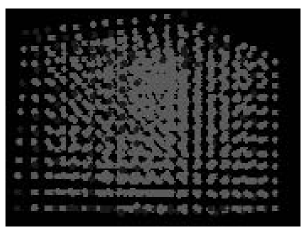
Figure 10: a-c: Selecting six image-imprints on the middle, left and right camera images. (d) associated 3D-cells connected by a simple skeleton. (e) Another skeleton representing a different set of six points. (f) A simple synthetic actor mimics the pose of the participant.



(a) Center camera



(b) Left camera



(c) Right camera

Figure 11: Active-space points for the three images.

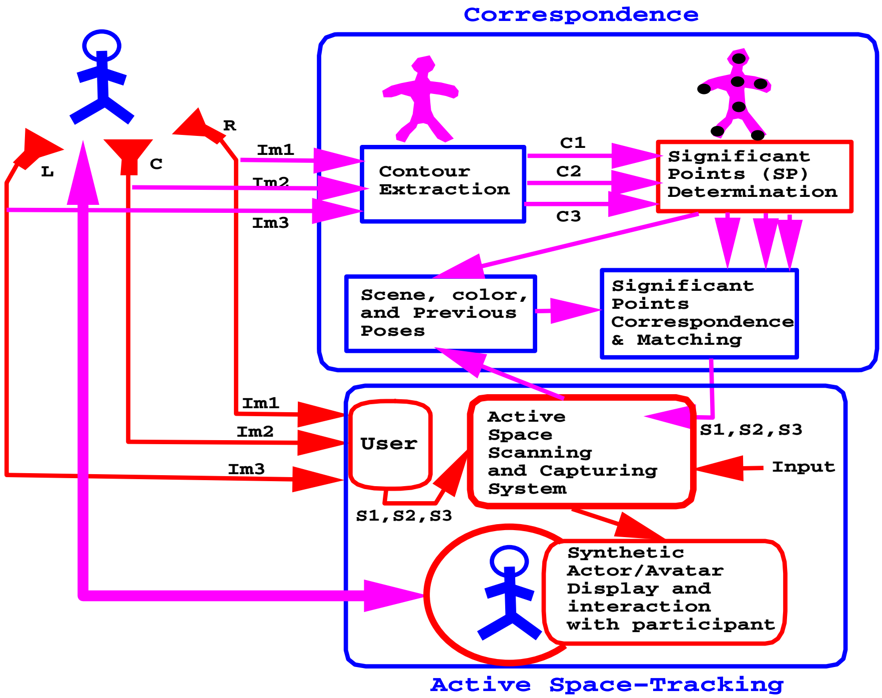


Figure 12: Block Diagram for the Scan&Track System

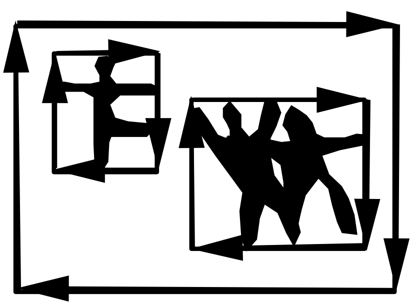


Figure 13: Multiple participants

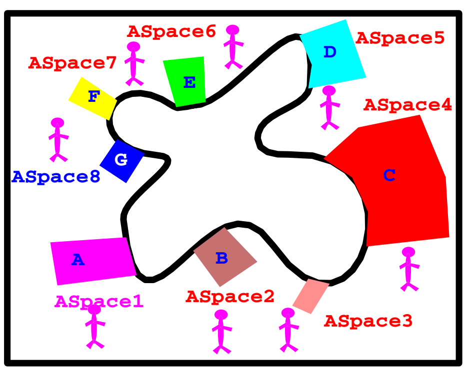


Figure 14: World of active-spaces

h t hniqu work u th r i nou h hi t in th proj tion o th point u to th m r po itionin th t th pth i rimin tion i po i l . nl th thr m r n l r i nti l or th ri i v ry wi it i hi hly unlik ly th t mor th n two li h v th m r orm y 1 2 n 3. n irn to our m tho thi woul m n th t th r olution o th li tiv p n to fin r or m r n l n to h n . t n on lu th t iv n thr imprint-point uniqu 3 ll-in x n oun . in i- t or olor -im r t http://www.cs.uccs.edu/~semwal/VW98.

5 Block Diagram of the Scan&Track System

h lo k i r m o th y t m i hown in i ur 12. h n r k y t m i n out i lookin -in y t m 1 . t on i t o *(a) the Correspondence* y t m n *(b) the Active Space Tracking* y t m.

h r r our u - y t m to th orr pon n y t m

(i) Contour extraction m r to n lyz n n outlin o th il- hou tt i xtr t rom th im . L t ontour 1 2 n 3 r pr nt th hum n- ilhou tt rom thr m r -im m1 m2 n m3 r p tiv ly. hi i w ll r r h r o omput r vi ion. h v v lop n-lin l orithm or utom ti xtr tion o ontour 0 30 31 .

(ii) Significant points determination xpl in rli r th om tri - imprint i xtr t y th om tri -imprint l orithm.

(iii) Significant points correspondence and matching h om tri - imprint o on ontour r orr pon to th om tri -imprint o ontour rom oth r m r -im pturin th m po . h out om o th m t hin l orithm i to provi n imprint- t tripl t (1 2 3) or v ry point in th om tri -imprint xtr t rom th m r -im .

(iv) Scene, color, and previous poses database h n in orm tion olor o om tri -imprint point n pr viou po r to u or r fin- in th orr pon n n m t hin o th om tri -imprint ro multipl m r -im .

h tiv p r kin y t m i u to tim t th po ition o point iv n th tripl t (1 2 3). h tiv p r kin y t m h th ollowin two m in u - y t m

(i) **Active-space scanning and tracking system** xpl in rli r w u th tiv - p in xin m h ni m whi h llow u to t rmin th lo tion o 3 point iv n it om tri -imprint (1 2 3). t thi tim w p i y th orr pon in point on multipl - m r im u in mou -pi k . n utur th point woul *automatically* n r t y th orr pon n y t m hown in i ur 1. r inv ti tin nov l p tt rn (. . h k r o r p tt rn) to utom ti lly fin th ri -point on th pl n r li urin pr pro in .

(ii) **Synthetic actor and/or avatar display** in th tiv - p in- xin m tho w h v n u ul in po itionin hum n-mo l or our i ility xp rim nt . n utur n v t r or ynth ti hum n tor i xp t

to r pli t th motion o th p rti ip nt. n utur w pl n to ompl t ly u- tom t th n r k y t m o th t p r on in 3 nvironm nt n tr k n r pr nt y n v t r. hi i th o l o our propo r - r h.

Multiple participants: l o xp t th n r k y t m to work wh n multipl p rti ip nt r in i th tiv - p hown in i ur 13. r n o multipl p rti ip nt n th ir im r r n h ll n in pur ly vi ion- y t m . or x mpl it i hi hly lik ly th t th om tri -imprint or h m r im will not h v n i nti l num r o point v n thou h m r r vi win th m n . hi oul u to o lu ion y oth r p rti ip nt in th . xpl in rli r orr pon n i mu h i r or th n r k y t m th tiv - p in xin provi v lu l 3 in or- m tion. hown in i ur 1 m h- plittin m y n ry wh n multipl p rti ip nt r pr nt 32 .

Ratio-theory: o r olv r m -to- r m orr pon n w ll orr - pon n ro multipl im o th m n w pl n to u th on pt o r tio th ory r l t to o y p rt . h i hin th *ratio theory* n t un r too y im inin t ilor m ur m nt. h xtr miti o on- tour n r l t ily i w t rt with th im n ion o th p rti ip nt hown in i ur 1 n 1 . rom on r m to noth r th l n th o th o y- xtr miti o th p rti ip nt n not h n . L t u um th t th om tri -imprint o two po h v n o t in hown in i ur 1. now n to orr pon point with point 1 point with point 2 n o on. h n th point r onn t i. . 1 to 2 to 3 n o on. n i ur 1 th urv l n th L1 tw n xtr mity n orr pon to th urv l n th L2 tw n n n o on. n p rti ul r it n i th t th r tio L1/L2 woul pproxim t ly qu l L3/L . o th orr pon n pro l m r u to m t hin n fin in t fit in m ll r h- p p n nt upon th num r o om tri -imprint point on urv rom m r -im .

Double verification: h n r k y t m llow *double verification* or v li ity o orr pon n . or x mpl i it i oun th t tripl t (1 2 3) r m t h w n l o v ri y it y m t hin th olor o 1 2 n 3 rom th im . th y r i r nt th n w o not h v m t h. n ition w n h v v ri ty o oth r m ur . or x mpl i th tim t po o n v t r i r ti lly i r nt th n th po in th pr viou r m th n it mi ht in i t orr pon n rror unl th p rti ip nt i movin xtr m ly t in th .

Avatars and Human Actors: in virtu l nvironm nt r xp t to popul t y oth v t r or hum n orm whi h r pli t th mov m nt o p rti ip nt n virtu l ynth ti tor who utonomou mov m nt i i- r t y omput r 23 19 . n th n r k y t m th tion o th p rti - ip nt r to tr k n m pp to th ynth ti hum n orm 33 3 35 36 37 .

6 Expected Significance of the Scan&Track System

i tru o ny vi ion- y t m th i rimin tion p ility o our y t m i limit y th phy i l- iz o th pix l in th m r -im . ow v r th y t m llow th u o multipl m r n thu multipl in i n mor ur t pr i tion o pth. On w h v t rmin 3 - ll or vox l v lu n n pproxim t lo tion th n w oul utom ti lly u noth r t o m r or mu h lo r n pr i look t th 3 - p n r th 3 -point. n oth r wor th tiv in xin m tho n ppli twi or mor . h fir t tim it woul u to fin hi h- r in in x n l t r w woul fin mor pr i in x y u in tho m r whi h h v th mo t t il vi w o th li n n r y r . h in orm tion out mor t il vi w woul r or urin pr pro in th m r rr n m nt o not h n urin tr kin . hu w r u tin th u o lo l n lo l m r . Not th t on m r oul lo l or on point n oul li t lo l or om oth r point in 3 p . tiv in xin i xt n i l n m n l to h r w r impl m nt tion; p i l purpo hip n i n or po ition- tim tion l ul tion . n ition i r nt li -p tt rn oul v il l or low n hi h- n u r or utom ti pr pro in . h *active-space indexing mechanism* m p 3 point in i th tiv - p to orr pon in proj tion on th m r -im .

mu t n w r on o viou qu tion how woul w l with th itu tion wh n th m r i pl with u h n ut n l th t ll th li proj t lin . n thi itu tion ri -lin m y r ly vi i l or v ry ut m r n l n th li will proj t lin wh n th m r -im pl n i p r- p n i ul r to th li . not th t it i hi hly unlik ly itu tion m r r *placed by us* n w n n ur th t non o th li r p r ll l to th vi w-norm l o ny m r .

h on r l t qu tion i n w till tr k ll o th tiv p with th r tri tion th t m r n not pl t ut n l w.r.t. li . h n w r i th t ll th t il o th t r ion n o t in y u in m r li htly w y n lo ly zoomin on th r o int r t. n ition i or om r on th m r n not mov th n th ori nt tion o th li n l o h n urin pr pro in to r t n w tiv - p in xin m h ni m. t i thi r om to h n th ori nt tion o m r n /or li whi h m k th tiv - p in xin m tho v r til . or omm nt r l t to r olution ur y r pon iv n ro u tn r i tr tion n o i ility r in 38 . h n r k i xp t to *accurate* n h v xtr m ly hi h *resolution* u v r l m r n pot nti lly zoom-in n provi hi h r olution tiv - p ir . h tiv - p in xin i on t nt tim wh n th num r o li n lin r on t nt. h *responsiveness* o th n r k y t m woul l o p n upon th tim it t k to l ul t imprint-point rom th m r -im . hi n to urth r inv ti t ut w not th t th orr pon n pro l m i mu h implifi u to th tiv - p in xin n th om tri -imprint l orithm. t i li v th t th orr pon n u - y t m (i ur 1) will th k y to r l-tim int r tion

n houl impl m nt in h r w r mu h po i l 39 . h tiv - in xin y t m i xtr m ly *robust* it n lw y fin 3 - ll or iv n imprint-point within th tiv - p . i u in 38 th n r k y t m u m r -im whi h r tt r in r olvin th *swimming* pro l m n ount r in virtu l nvironm nt . irtu l o j t t n to wim u o th li ht v ri tion in tim tin th 3 po ition o th tr k -po ition. u o th tiv - p in xin th m orr pon in point on th im will lw y pro u th m r ult n th r or th wimmin pro l m i xp t to on i r ly r u .

urin pr pro in m r n zoom in n out n pl p n - in upon th u r wi h. ultipl u r n tr k th m 3 p upon th ir own hoi o li n ot p tt rn . N w m r n u to mor tiv - p ir .

h tiv - p in xin m tho i uniqu n n w n it i n tt mpt to olv th orr pon in pro l m ro multipl m n i l o n w m tho to tim t 3 po ition. ontour xtr tion m tho in th propo l fin tho point on th hum n o y whi h r mo t vi i l n th r or r mor lik ly to pr nt n -point in ontour xtr t rom m r -im .

Occlusion: n th n r k y t m w pl n to look into p t vi o- r m to r olv or t l t know th t th om thin whi h w vi i l or i not vi i l now. n thi th propo n r k y t m will ontinu to tr k tho n -point whi h r vi i l (. . h n t). h point i thi th t th n r k y t m i ro u t th om tri -imprint h n rom r m -to- r m .

7 Can VEs Really Understand Humans

h n r k i xp t to hi hly i tri ut y t m with v- r l n r k tiv - p phy i lly i tri ut . i ur 1 how v r l tiv - p . lthou h tiv p n r itr rily l r nou h priv y to th hum n-p rti ip nt i provi no tr kin n on out i th tiv - p . in w xp t v r l hum n-p rti ip nt to int r tin in thi hi hly i tri ut it i ppropri t to k ( ) n mor pow- r ul th t urin hin ( ) ( ) n r lly un r t n th hum n p rti ip nt

h v th ollowin o rv tion (i) l r nti lly mor pow r ul th n th urin hin mo l u o th non-lin rity intro- u y hum n-p rti ip nt . y llowin multipl hum n to int r t in th phy i lly i tri ut m nn r r xp t to h v in non-lin r w y u hum n h vior i nti lly non-lin r. (ii) lthou h r non- lin r n th r or xp t to mor u ul th n in lin with hum n-int r tion it i our opinion th t m y *not* l to *completely* un r t n th *human participants.* lthou h w n not un r tim t th hum n- r in w h v impl y t omp llin r um nt hum n r t in *non linear abstraction.* oo x mpl o non-lin r tr tion n oun

wh n w tr v l. ow m ny o u r lly inv t ny tim thinkin out th pl n flyin oon w o r th pl n w r lr y m kin pl n to wh t w will o wh n w rriv t our tin tion. n oth r wor w h v lr y tr t th tu l tr v l (w um th t w will rriv t th tin tion ly). o l rly t t our o rv tion m y llow u to p r orm non-lin r t k how v r th y m y not un r t n th hum n-p rti ip nt n l to pr i t with rt inty wh t th hum n-p rti ip nt w nt to o t th v ry n xt mom nt.

8 Conclusions and Final Comments

h n r k y t m voi th ompli t m r li r tion op r tion n th i tortion u to m r proj tion r utom ti lly voi . h y - t m wh n impl m nt woul l l tiv -in xin or th m 3 - p oul v lop or oth th low n th hi h- n y t m . n ition th tiv - p volum i l o l l . h qu liti m k th n r k y t m i l or utur hum n- nt r ppli tion .

h tiv - p in xin m tho provi r m work or un n um r 3 tr kin upon multipl vi o qu n . h tiv - p in xin m tho o not r quir ny m r li r tion or m r ori nt tion p r m - t r or tim tin th po ition. iv n th imprint- t o point th tiv - p in xin m tho t rmin th 3 - ll or vox l o th tiv - p ont inin th t point in on t nt tim . h m tho provi p -lin rity within th 3 - ll n llow lin r int rpol tion to u or tt r po ition tim t . h pr pro in l orithm i impl n n ily utom t . l n r li n r itr rily l r or m ll n n h v fin r or o r ri p tt rn . n utur w pl n to u mu h l r r 8 t y 10 t pl n r li (w ll) with fin r ot p tt rn.

h propo n r k y t m i u ul or i tri ut . ultipl u r n tr k th m 3 p upon th ir own hoi o li n ot p tt rn . N w m r n u to mor tiv - p ir . h n r k y t m n u or p r on l tiv - p in ront o th u r r n y pl in thr m r t th top o th monitor. h pr pro in l orithm i impl n n ily utom t . h n r k y t m n l o u lon with oth r xi tin tr kin t hnolo i . m r r xp t to mount on th w ll n out o th w y o th p rti ip nt th tiv - p in xin m tho i uit l or hum n- nt r ppli tion .

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CyberGlass: Vision-Based VRML2 Navigator

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Abstract. In this paper, I will show an example of a VRML 2.0 interface for a portable device. CyberGlass uses a "video recording metaphor" to examine a 3D virtual world. The critical problem is to change a viewpoint in the virtual world based on the movement of a portable device. We have solved this problem using data obtained from a CCD camera. Using a CCD camera to detect motion enables us to develop a compact device. We developed a prototype of CyberGlass to provide an intuitive access to 3D world.

1 Introduction

Given the explosive growth of the Internet and progress of Internet technology, it will be necessary to develop technologies that promote various types of access to content. Existing access styles are based on HTML and JAVA. VRML 2.0 is a comparatively new format for content publishing, which enables us to represent information as a collection of 3D mobile graphical objects. Unlike text-based schemes, this type of representation can present information which has not been explicitly coded by the producer. Even the relative locations of objects can be meaningful. If objects move, information will change over time. Thus, we need to discover an application domain where VRML 2.0 is an attractive alternative.

We are attempting to identify a plausible context in which we might naturally access a 3D virtual world. This will help suggest a style of content publishing appropriate for VRML 2.0 moving worlds. One plausible scenario is to use VRML 2.0 information in a place for which a 3D model is available. Suppose we are visiting the Louvre museum and its corresponding 3D model is available on a portable device. We may access appropriate information for each work of art at the appropriate moment. It would be useful if the view displayed on a screen of the device matched an image being observed. This is because the view allows us to find relevant information quickly.

To make this scenario realistic, we need to solve two problems: one is to determine the location we are looking at and the other is to detect motion of a device. For the first problem, we can assume that infrastructure support will provide us with a global position. For example, NaviCam uses bar-codes pasted on target objects for which we

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can retrieve information (Rekimoto, 1995). We are currently focusing on the second problem, namely, detecting a device's ego motion.

As described above, our final goal is to record our trajectory in a visiting place and to replay it using a VRML 2.0 browser with an appropriate 3D model of the visiting place. Through our work towards this goal, we have recognized that ego-motion detection itself provides a good user interface for VRMK 2.0 browser. In general, a gyroscope is better hardware for identifying an ego motion of devices such as head-mounted displays (HMD) in virtual reality environments. We chose a CCD camera, however, mainly because we do not want to add more hardware to a small computing device for simplicity. Again, our final goal is to use a portable device in a real world to record the changes of our viewpoint in a visiting place. A CCD camera could be used to detect a global landmark. Thus, our challenge here is to see how well we can solve our problem using a CCD camera only.

2 CyberGlass: Design Issues for Portable Interfaces

We designed CyberGlass for users of portable computers, which are, in general, smaller, slower, and have less storage than desktop systems. In order take full advantage of these computers, we identified the following design issues:

– intuitive operation for examining the world: CyberGlass is a user interface designed to help us examine the world. When we look around the world, we normally turn our head or move our eyes. In a desktop environment, however, because of this restriction in the position of the display, that type of motion is impossible. Instead, we change our viewpoint by using pointing devices such as mice or touch sensors. When we carry a device with a display, the restriction disappears. We can move it to right or left while looking at its display. This is typical in video recording. We move a video camera so as to keep the things we want to record in the center of the display. Since we are already familiar with the action of filming a video, we can use this action as a metaphor for the user interface. We shall call this the "video recording metaphor." In fact, the main idea of CyberGlass is to capture images in a 3D virtual space as if through a video camera or a water glass in the real world. Note that this is not unusual in VR environment, but we are trying to apply the same type of idea to portable computers using computer vision techniques, rather than gyroscope.
– inexpensive movement detection: One of characteristics of portable computers is their ease of use – we can use them anywhere and anytime. Nevertheless, they have a serious deficiency. In general, to save battery consumption, portables have less CPU power and less memory. For this type of computer, simpler algorithms are preferable in order to reduce computation time. With respect to ego-motion detection, several computer vision algorithms are available. One is the optical flow algorithm. Several studies are based on optical flow (e.g. (Horn and Schunck, 1981) (Sundareswaran, 1991) (Barron, Fleet, and Beauchemin, 1994)). One particular example of the optical flow algorithm is shown in (Ancona and Poggio, 1993). This algorithm is said to be well-suited to VLSI implementation. Therefore,

compared with other optical flow algorithms, this algorithm is worth considering for portable computers. Optical flow computation, despite its complex calculation, can never reduce errors to a negligible level. If we can limit the working environment, we can expect that simpler methods such as frame difference could work well. Simple frame difference is much less expensive than optical flow algorithms. Fortunately and strikingly, in our experiment, the simple frame difference algorithm works very well when target images have a clear contrast in color depth a condition that we can generally expect around picture frames in museums. Therefore, we decided to use simple frame difference for a prototype system while we continue to investigate the other algorithm for further developments.

– approximation of rotation angle: Movement of a device is perceived as linear movement, even if we rotate the device. We are interested in rotation here. Therefore, we need to project linear movement to rotation.

Fig. 1 A Prototype of CyberGlass.

3 Implementation

A prototype system of CyberGlass was developed based on the SONY CCD camera MC-1 and TOSHIBA portable computer Libretto50 (Pentium 75 MHz, 32MB). The CCD camera is arranged so as to match its direction with user's gaze. A picture of this system is shown in Fig. 1. This system consists of two software modules: a motion detection module and a 3D virtual world's viewpoint control module. A block diagram is shown in Fig. 2. Hereafter, I will explain how this system works.

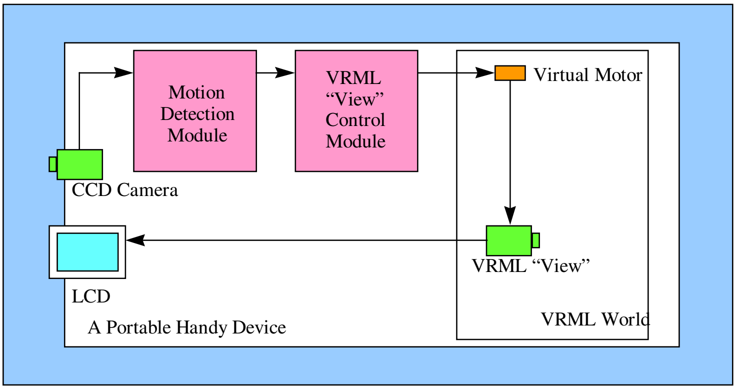


Fig. 2 A block diagram of CyberGlass

3.1 Motion Detection Module

The image captured by the CCD camera is stored in a frame buffer. After grabbing two successive frames, we perform an optical flow calculation. As I mentioned above, the method used is a frame difference algorithm. We can calculate a center of gravity for changes of all the pixels at time t by comparing two serial frames of images from a CCD camera. Let us call the center of gravity (x, y). After the next frame is received, we perform the same calculation to obtain the center of gravity at t +1. We call this (x', y'). From these centers of gravity, we can obtain (Δx, Δy), where $\Delta x = x' - x$, $\Delta y = y' - y$.

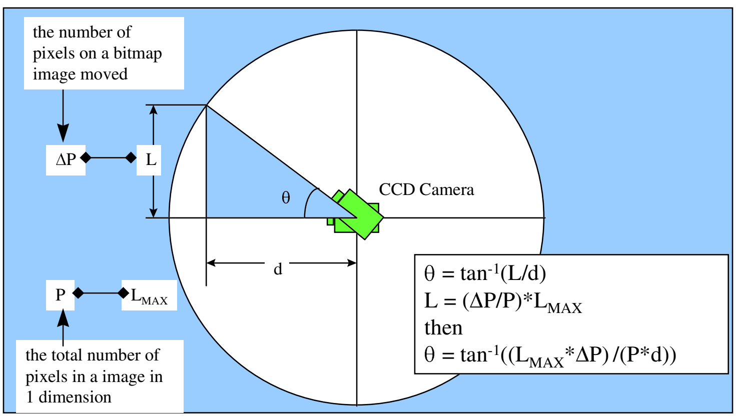


Fig. 3 Approximation of rotation angle of a device

3.2 3D Virtual World's Viewpoint Control Module

Once we have obtained the movement of the center of gravity (Δx, Δy), the 3D virtual world's viewpoint control module can rotate the viewpoint in a 3D virtual world by the following angle θ:

$$\theta = \tan^{-1}((\Delta P * L_{MAX}) / (P * d)). \quad (1)$$

where ΔP is either Δx or Δy in pixels and P is either the bitmap width or height in pixels. L_{MAX} is a distance in meters corresponding to P and d is a distance in meters to a target object in front of the device (See Fig. 3 in detail). The result is then represented on the display.

As described in the introduction, our final goal is to use a portable device in a visiting place. Therefore, d must be a correct distance from a CCD camera to a target object. In a real environment, by adding a special sensor hardware (e.g. an ultrasonic sensor) to the CyberGlass, it might be possible to obtain an exact distance d. In the case of a VRML 2.0 browser, however, we do not have any target. D, in this case, is the distance from our eyes to a virtual referential object in a virtual space. Thus, we need to set d to a constant.

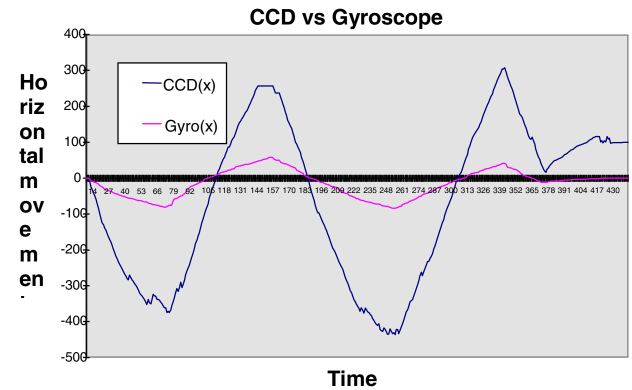
4 Characteristics of an Experimental System

We conducted experiments with the CyberGlass equipped with both a CCD and a gyroscope for comparison. Fig. 4 shows traces of horizontal and vertical movement of the viewpoint according to the movement of a CyberGlass. The gyroscope provides almost the exact angle from an initialized position, whereas the CCD uses approximation calculated by equation 1. Even so, it should be noted that the approximated moving angles have nearly the same tendency as of the gyroscope. In particular, the approximated moving angles successfully return to 0 degrees whenever the gyroscope says that it is 0 degrees.

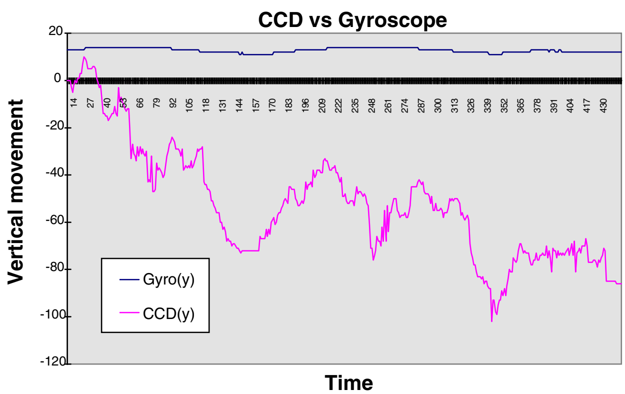
Unfortunately, when we consider both the horizontal and vertical axes, and we move a CyberGlass only in horizontal direction, a problem arises as shown in Fig. 4 (b). Although we did not move it in vertical direction, the angle approximation module automatically accumulates erroneous movement caused by noise. As the result, the angles went down towards the ground. We can avoid this by a forced solution. Namely, a CyberGlass can suppress updates of angles of either direction by detecting which direction has a major movement. If we need more degrees to be detected at one time, we will need to consider a more complex algorithm presented in (Roy and Cox, 1996).

5 Conclusion

We designed a VRML 2.0 interface for a portable device and developed a prototype system, called CyberGlass. This system is designed based on a “video recording metaphor”. Namely, we can look around a 3D virtual world as if we were looking around the real world using a video camera. The current implementation has been tested in an environment where lighting is relatively moderate and objects are evenly distributed all around the environment so that any movement can be detected according to the motion of the handheld device.



(a)



(b)

Fig. 4 A Trace of Horizontal/Vertical Movement.

One frequently asked question is why we do not try to detect forward or backward movements in this interface. It may be interesting to note that, according to our forward/backward movement with CyberGlass, the viewpoint inside a 3D virtual world changes. Nevertheless, I believe that, with respect to forward/backward movement, it would be better to use a push button interface rather than to change our standing position. One reason is the limited space available for the user to move. The other reason is that we are familiar with the metaphor of “driving a car” using an accelerator.

This is a report of work in progress. In future work, we would like to integrate this system with NaviCam so as to determine a global position of CyberGlass in order to produce a platform for more advanced applications.

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Work Task Analysis and Selection of Interaction Devices in Virtual Environments

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Abstract. The user interfaces in virtual environments depend on the work task given by specific applications and the adaptation to the human senses. This paper describes a method for work task analysis and selection of interaction devices for the design of user interfaces in virtual environments. The method takes into consideration degrees of freedom in the interaction process and the human senses. Characteristic is the systematic process for the designer. The method will be described and the results in an experimental environment discussed.

1 Introduction

Over the past few years, Virtual Reality (VR) has grown from an experimental technology to an increasingly accepted standard part of the business process. VR offers significant benefits as a problem-solving tool in various applications. It gives the user the feeling of being a part of the application to see and examine products, plans or concepts before they are realized [1].

The starting point for problem-solving in Virtual Environment (VE) is choosing the technological configuration for a VR system. It is mainly the application, which drives the need for particular technology requirements. These requirements are the computer hardware, VR software and the configuration of interaction devices. Especially the adaptation of interaction devices has a close influence on the human performance in problem-solving processes.

From the beginning, VR technology has produced a broad variety of interaction devices. Some, like force-feedback systems, for use in specific work fields and others for more universal use. Therefore the designer has no easy choice. The result is, that in expert interviews the user-interface of VR systems is rated unsatisfactory because of its user-hostility [2].

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2 Conditions

One characteristic of VR technology is multi-modal communication between a user and a Virtual Environment. A wide variety of VR interaction technology for perception and manipulation in VE is available for use in practical applications. They differ in performance, information throughput rate or user-friendliness. For example the visual sense can be served by a common monitor, a head-mounted display (HMD) or a CAVE™-system. The choice depends on the necessary degree of perception and the work tasks in VEs. To balance both factors is the job of the designers of the user interface. VR applications commonly disregard human factors. Most designers have not examined the requirements of psychology and perception [3].

The main requirements for the interaction devices are driven by work tasks for system and application control. The required interactions are so-called necessary interactions in VE at configuration and run time. The task of the designer is to fulfill these necessary requirements with the available interaction devices and to take into consideration the human factors for perception and manipulation processes. Several researches have reviewed the important ergonomic issues in VR. But it is rare to find ergonomic guidelines for designing VEs and especially the configuration of interaction devices. The goal is to gain a maximum in human performance for a given work task. Experiments show, that the terms of interaction, presence and interaction devices are very important issues in human performance [4]. Sheridan stated that the determinants of sense of presence are: the richness of sensory stimuli, simultaneous viewpoint changes with head movements, the ability to handle objects inside the virtual environment and the dynamic behavior of the moveable objects [5], [6]. A breakdown of sense of presence can occurs because of the weight of the HMD, time lags or poor balanced configuration of interaction devices in VE. The result is a reduce in human performance. To gain an optimum in performance a method for configure interaction devices has to take into consideration the factors of perception by given requirements.

3 Method

The configuration of interaction devices has to take into consideration the requirements of the work tasks (necessary interaction of the user), the degrees of freedom (DOF) of the interaction devices in VE (possible interactions) and the combinations of interaction devices [7], [8]. The necessary interactions of users will be separated from the specific work tasks of system and application control and classified by the method of Ware-MacKenzie [11]. Here the interactions will be classified by DOFs. Multiple DOF devices such as 3D or 6D trackers and glove input devices are excellent choices for multiple DOF tasks such as viewpoint or object placement by gestures. Similarly, 2D devices are well suited for 2D tasks such as drawing or pointing on a CRT. The same classification of the interaction devices allows a first assignment of interaction devices to the work tasks by DOFs. By the use of grading and comparison the final combination of interaction devices will be chosen by taking the allowed combinations of interaction devices with their mutable

combinations into consideration (Fig. 1 shows the methodical steps to find an optimized combination of interaction devices).

(1) Classification and grading of necessary interactions for controlling and observing the VR system based on DOFs.
(2) Classification and grading of necessary interactions for the application in the VE based on DOFs.
(3) Classification and grading of the interaction devices based on DOFs.

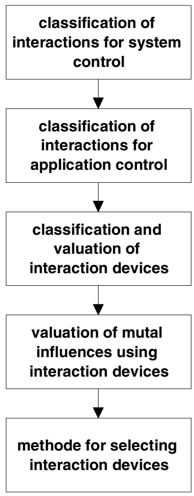

Fig. 1. Method for task-analysis and selection of interaction devices

Problems arise, when using interaction devices for tasks that do not have the same number of DOF. For instance, specifying the 3D position and orientation of an object with a mouse is difficult because one can only modify two DOFs at a time. Conversely, using higher DOF devices for lower DOF tasks can also be confusing if the interaction device is not physically constrained to the same DOF as the task.

(4) Grading of the combination of interaction devices with input/output functions.

Not all combinations of interaction devices are meaningful. For instance the use of a computer mouse in combination with a HMD make no sense.

(5) Choice of interaction devices by the use of the grading and comparison.

The choice of interaction devices begins with the comparison and grading of input and output devices with the necessary interaction for each DOF. The result is a table of interaction devices with a grading depending on system and application relevant work tasks. Further the tables will be used to build up matrices with the combinations of input and output devices for system and application work tasks. A first rough ranking will show, how use-full each interaction device is for a specific work task separated for system and application work tasks). Because not all combinations are useful, the matrices have to be compared and valued with the possible combinations

of interaction devices, described in step 4. The result is a ranking, which interaction device fits best the given system or application requirements. The separate ranking for system and application work tasks could lead to an overlap of two different work tasks to the same human sense. This is sometime very disturbing for a user. For instance, printing system information in the view field of the user can be very disturbing in an immersive environment. Such overlaps can be solved by the mapping one function to another human sense. Here, system information can be presented as acoustic signals or as a speaking voice.

4 Experimental Environment

The method will be evaluated in an experimental environment for virtual prototyping [12]. A VE has to be designed to fulfill design, validation and training requirements in safety engineering. Safety systems are very complex and the development a difficult task for design engineers [9]. A lot of rules and laws have to be regarded. Mechanical and electrical know-how is necessary for the technical design, ergonomic and psychological know-how for the control design. Most accidents occur because of errors in the control design. Missing ergonomic aspects lead to high workload and low concentration. The test environment for the virtual prototyping of safety systems consists of a robot working cell with two drilling machines and two separate working stations. A worker has to interact with the system by programming or reprogramming the robot system, by exchanging the storage systems and by the repair of male-functions of the robot system, the drilling machines and the working stations (Fig. 2 shows the geometrical model of the robot working cell with the safety system components).

Fig. 2. Geometric model of the experimental environment

5 Results

The process of virtual prototyping consists of an order of work tasks with different tools. Each tool is well adapted to the problem-solving process [10]. In a VE the user controls these tools by the use of interaction devices. The use of interaction devices for problem-solving is not constant but differs from the work task and the DOF the device in VE.

The method for work task analysis and selection of interaction devices has been tested in the experimental environment. The first step is to define the work tasks for VR-system and application control and observation. Table 1 and 2 show the work task separated into the required DOFs, input and output interactions. The grading of the tasks is a subjective ranking with 5 levels of importance.

Table 1. Classification and grading of required interactions for system control and observation in virtual environments based on degrees of freedom

degrees of freedom	input interactions		output interactions	
1	text input binary input	o ++	text output binary system condition	o +
2	point at objects selection in virtual menues	++ ++	menue output system conditions system parameter output	+ + o
6	pointing input spatial navigation selection in virtual menues	++ ++ ++	menue output	++
	-- very unimportant / - unimportant / o not affecting / + important / ++ very important			

Table 2. Classification and grading of required interactions for application control based on degrees of freedom

degrees of freedom	input interactions		output interactions	
1	input object parameter input object relations binary inputs	- - +	output object parameter output object relations binary object conditions	- -- -
2	input object parameter input object relations object selection selections in virtual menues	++ o + ++	output menues output object parameter output object realations simulation results	++ + + ++
6	input object parameter input object relations object selection input spatial navigatin selectins in virtual menues	+ ++ ++ ++ +	ouput menues output object parameter output object relations simulation results	++ ++ ++ ++
n	communication between users	+	communication between users simulation results	+ ++
	-- very unimportant / - unimportant / o not affecting / + important / ++ very important			

This method guarantees, that important work tasks will be mapped to high ranked interaction devices (Table 3). Classification by DOF of the interaction devices is shown in Table 3. The process is the same as for the work tasks before. The grading ranks how suitable the interaction device is for the required immersion and presence in the VE.

Table 3. Classification and grading of interaction devices based on degrees of freedom

degrees of freedom	input devices		output devices	
1	bio signal key switch keyboard	+ o o +	vibration output signal light buzzer	- - -
2	eye tracking computer mouse	+ +	monitor	++
6	tracking system space ball Space Mouse™ flying joystick 3D-pencil Immersion Probe™ mechanical kinematic	++ + ++ ++ + + +	monitor with shutter glasses projection with shutterglasses CAVE™ system with shutter glasses headmounted display BOOM™ system retina projektion system stereo headphone speaker system mechanical kinematic motion platform	- - ++ ++ ++ ++ ++ ++ ++ -
n	data glove exoskeleton microphone video camera	++ ++ ++ ++	exoskeleton	++
-- very unfit / - unfit / o not affecting / + suitable / ++ very suitable				

The classification of interaction devices will be rated by the highest possible DOF. The use of interaction devices with a higher DOF than the linked work task is possible. All DOFs of a dataglove are for instance hardly ever used. Further is it possible to combine different interaction devices with lower DOF than required form the work task. Not all combinations are however useful. Table 4 shows the combinations of input and output devices with their subjective grading.

The final selection of the interaction devices will be done by grading and comparison. The steps are as followed:

(1) To select interaction devices, the designer has to combine and value the interaction devices with the necessary interactions of the work tasks for system and application control and observation. The results are tables with ranked input and output devices sorted by system tasks, application tasks and DOF.
(2) As not all combinations of interaction devices are useful, all interaction devices have to be valued with the results of Table3 (mutual influence of combinations). The result are rankings for all interaction devices sorted by system tasks, application tasks and DOF.
(3) The last step is a check if there is an overlapping of two different work tasks to the same human sense. If there is a collision, one work task have to be mapped to another human sense.

For a virtual prototyping VE in safety engineering the described method leads to the following combinations of interaction devices (Table 5). The result is a rank list for the interaction devices sorted by the DOF, system (sys) and application (app) related requirements.

The VE for virtual prototyping is a immersive environment based on HMD and stereo speaker or headphone as the main output devices. The main input devices are the dataglove or flying joystick combined with a tracking system. An exoskeleton would add tactile and force perception to the VE. The rank for input devices shows that immersive environment is not very useful for the system relevant tasks . To solve

this problem a second person should guide the person who does the validation. This second person controls the environment with conventional input devices. The monitoring of system relevant information is possible and helpful in immersive VE.

Table 4. grading of mutual influences between interaction devices

		output devices													
		monitor with shutter glasses	projection with shutter glasses	CAVE™ system	headmounted display	BOOM™ system	retina projektion system	stereo headphone	speaker system	exoskeleton	vibration output	motion plattform	signal light	buzzer	mechanical kinematic
input devices	tracking system	+	+	+	+	-	+	+	+	-	-	o	o	o	o
	space ball	o	o	o	+	o	o	+	+	-	-	o	+	+	+
	flying joystick	o	o	o	+	o	+	+	+	-	-	o	+	+	o
	3D-pencil	o	o	o	+	o	o	+	+	-	-	o	+	+	-
	data glove	o	o	o	+	o	+	+	+	-	-	o	+	+	-
	exoskeleton	o	+	+	+	o	+	+	+	+	-	-	+	+	-
	computer mouse	+	-	-	-	-	+	+	+	+	o	+	+	+	o
	eye tracking	o	-	-	-	-	+	+	+	+	o	+	+	+	o
	bio signal	+	+	+	+	+	+	+	+	o	o	o	+	+	+
	microphone	+	+	+	+	+	+	+	+	+	+	+	+	o	+
	key	o	o	o	+	+	+	+	+	o	-	o	+	+	-
	switch	o	o	o	+	+	+	+	+	o	-	o	+	+	-
	keyboard	+	o	o	-	o	+	+	+	-	-	-	+	+	+
	video camera	+	+	o	-	o	+	+	+	o	-	-	+	+	o
	Immersion Probe™	+	o	o	+	o	-	+	+	-	-	o	+	+	-
	Space Mouse™	+	o	o	+	o	-	+	+	-	-	o	+	+	-
	mechanical kinematic	+	o	o	+	o	-	+	+	-	-	o	+	+	
	- not usefull / o limited use / + usefull														

The ranking of the devices with DOF 1 and 2 in Table 5 shows a correlation. This is not surprising because the exercises can be solved with non VR related devices. DOF 6 and n show a significant difference. In this cases the exercises are related to spatial perception and action. The tendency to VR related devices is reasoned by the application related exercises for virtual prototyping in safety engineering.

Table 5. Rank of interaction devices for system and application control

degrees of freedom	input devices	rank sys	rank app
1	bio signal	3	3
	key	2	2
	switch	3	3
	keyboard	1	1
2	eye tracking	3	1
	computer mouse	1	0
6	tracking system	4	1
	space ball	5	3
	Space Mouse™	1	3
	flying joystick	2	2
	3D-pencil	6	5
	Immersion Probe™	7	7
	mechanical kinematic	3	6
n	data glove	0	1
	exoskeleton	0	4
	microphone	0	2
	video camera	0	2

degrees of freedom	output devices	rank sys	rank app
1	vibration output	2	2
	signal light	1	1
	buzzer	1	1
2	monitor	1	0
6	monitor with shutter glasses	5	4
	projection with shutter glasses	10	9
	CAVE™ system	6	6
	headmounted display	2	2
	BOOM™ system	9	9
	retina-projection system	4	5
	stereo headphone	1	2
	speaker system	1	1
	mechanical kinematic	8	8
	motion platform	7	7
n	exoskeleton	0	1

6 Conclusion

The use of the method for task-analysis and selection of interaction devices have been tested in an experimental environment at the Fraunhofer IPA. Therefore a VE has been designed for the specific requirements of virtual prototyping work tasks in safety engineering. Design, validation and training work tasks selected work tasks.

The method takes into consideration the classification of work tasks (system and application relevant), classification of interaction components and the mutual influences of combinations of interaction devices. Its uniqueness is a straight forward process to select interaction devices depending on immersion and physiology of the human senses.

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Effect of Stereoscopic Viewing on Human Tracking Performance in Dynamic Virtual Environments

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Abstract. In this paper, we present the results of a human factor study aimed at comparing the effect of stereoscopic versus monoscopic viewing on human tracking performance. The experimental paradigm involved tracking and grasping gestures toward a 3D moving object. This experiment was performed using different frame rates (from 28 frames per second (fps) down to 1 fps). Results show that monoscopic viewing allowed stable performance (grasping completion time) down to 14 fps. Stereoscopic viewing extended this stabilty to 9 fps, and decrease task completion time by 50 % for frame rate under 7 fps. We observed that stereoscopic viewing did not much increase performance for high frame rates.

1 Introduction

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J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 97–106, 1998.

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vi u i y vi u i p y y m (i) m (ii) g p i up
n (iii) y .

m i w - on o v i min num
o im g n y ompu g p i y m p on . up
o vi u i y vi u i p y y m i mo impo n mpo v i
n m . o in n i i p y y m m o 0 z
u n up o z n y m p n 15 on u iv i n i
im g o n o i ng ny o m n in n n n
p n 15 on u iv im g o n w n . u i y m n p n
on y ou im g p on . m jo o in mining up i
ompu ion omp xi y o vi u wo .

y in vi u i y y m o wo yp ompu ion n
n o . ompu ion y i m jo o in mining up
o i p y y m. n o y i im qui o n o y m o
p iv mov m n m y u qui up ing i p y. n o
y n ompu ion y i iv . o in n y m w i
10 z up n 150 m n o y wou p o u m ximum y
o 250 m w n v u ’ mov noug o qui yn i o
n w im g o vi u wo .

o ow g p i up vi u o j pp o mov in i
p i jump p in 3- p y in - ion i n n in im
y in - ion in v . n um n vi u y m o i g
g p w n ion w n o j i u y p n y u ing p io-
mpo in po ion (p io- mpo in po ion imp ion o
mo ion om qu n n o ion y im g y on u ing mo ion
p in w n ion u y p n).

yon i p nom non o pp n mo ion i v n w
p y o ogi inv ig ion o imp i ion o i pp n on inui y o
o p o vi u p p ion. n p i u i n o j moving in i
p i jump i p iv i in on inuou mo ion w o i imp y ou
p iv vi u i ion o o j ny on in n o im ? v
i in in o vi n poin o on u ion vi u i ion o
o j in i um n m y on i wou o upying i i
w y in on inuou mo ion. u pp n y moving o j n o
moo ing y mov m n in w i y on inuou y ng i po i-
ion in m w y i o o p on inuou y moving g . Mo ov
om on ow in mi n y mp vi u in o m ion m y u
on inuou y in on o o mov m n 3 . ow v in o m ion
om n pp n y moving g i g y in ing p io/ mpo
in v w n u iv g p n ion wi om poin w
y wi no ong o ow g on inuou y u wi mov om po i-
ion o po i ion in i o . Mo ov wi om poin w

n wi no ong o ow g on inuou y u wi o mov om po i ion o po i ion.

n iv inv ig o up on um n p o m n in m nipu ion u ing mono opi i p y. u j w o p o m wo mo m nipu ion u ing n gonn -2 v n- g -o - om vo m nipu o . o m n on w n inv o im qui o o o y. g p i up w ju o 2 1 o p . n iv o v p o m n w n up w ow 1 p 5 . M imino n i n omp m nipu ion p i i y o i vi ion v u mono opi vi o i p y in imp o -in ion . y oun m n omp ion im opp m i y up ow 1 p . ow v u i u on y mono opi i p y . n i in ugg vi u p n ion o p p iv i - p y up ow m y n igni qu n y o in u ion o ino - u i p i y 7 . g n n v y o v p ju gm n mo u wi yn mi i p i y up ow n 2 p . i ug- g o opi i p y m y up io o mono opi i p y ow up .

om i u i wi vi ion i p y ow o opi i - p y omp o mono opi on i no p ovi igni n v n g in p o ming om m nipu ion 9 10 11 . Mo n u i ow- v in i o p o m n w up io o mono opi un mo on i ion w i moun o imp ov m n v i wi vi i i i y n ning o 12 13 . u ow v n g o o- opi vi ion i p y om p onoun wi in n omp xi y n o j vi i i i y.

Mono opi n o opi g p i i p y w omp y mp oying - xi -m nu ing 1 15 . u w on i n wi p viou vi ion i p y u in i ing o opi g p i i p y i g n- y p mi up io ing p o m n w i mono opi i p y ow quiv n p o m n w n y w n wi qu vi u n n - m n p u u p p iv g i .

2 Experiment

n i xp im n w inv ig o o opi vi wing on um n p o m n in ing/ qui i ion o 3- moving vi u o j o i n g p i up .

xp im n y m i u i i u in (ig. 1). oo y- oup i n - v i u ow o i i u ion o ompu ion o imu ion on wo wo ion . On un wo ion i i o ing n i ing g ov n m in ining in o m ion on o j in vi u wo . n 755 wo ion i i o g p i n ing n i p y m o 2 p . 755 mono opi i p y (12 0x102 pix o u ion) w p y p i o moni o wi 120 z

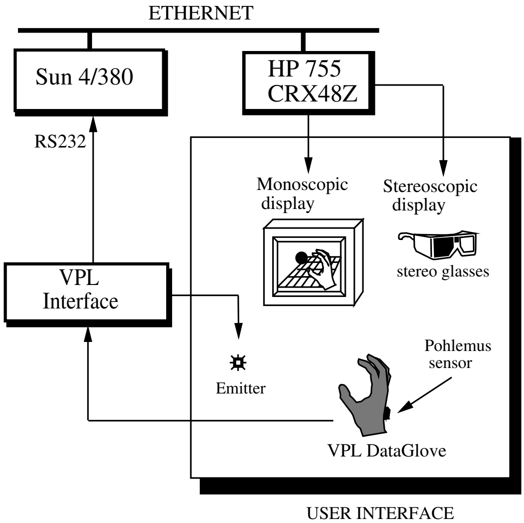

Fig. 1. xp im n y m i u

m (qui o u o o g). ov TM i u o m u n g u 1 . o mu TM n o w i i moun on o g ov n mi 3- w i po i ion n o i n ion 17 . u y o o mu TM n o (o TM mo) i ou 2.5 mm n ion n 1^o in o ion.

2.1 Visual Display

n o opi vi ion ou in u wo ig y i n vi w o wo (n y o y) in o on o n 3- im g . n mono opi g p i i p y ing 2- im g i p n o o y .

um n in in p 2- mono opi im g 3- im g y u i izing p u (p p iv o u ion mo ion p x n o on). n o opi g p i i p y wo p im g g n wi ig y i - n vi wpoin p n o o y .

xi i n niqu o p n wo p im g o o y 15 . Ou xp im n u ing n wi n ing (im -mu ip x) n ig vi w n u g . n ing n ig im g yn oniz wi op ning n o ing ion o u oug n in ( ) on o (ig. 2).

2.2 Virtual Environment

xp im n vi u nvi onm n (ig. 3) i ompo o w in p p iv vi u n n o m (g). i u p

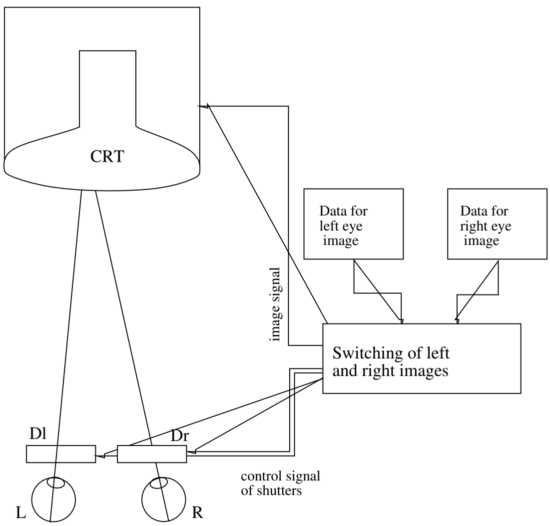

Fig. 2. ino u vi wing y m u ing im i p y o n ig im g

u u v i p oj ion o o j “ ow ” n g i g oun n in o u in nvi onm n o imp ov p p p ion. vo um o vi u oom i ou 1 m^3. vi u n i m o 129 po ygon n m in m i um n n . i m o 72 po ygon . o o j p og mm in o “ i p y i ” u ing p i i y 1 ou u ing n ou u ing wi on ig ou .

2.3 Protocol

i w un o ow g pp in vi u oom wi m v o i y (25 m p on). u j w n in u o moving g n g i qui y po i . o giv n xp im n ion u j p o m wi 15 on p io w n i . ion on i o 10 i .

u j w o y -vi u i p y i n w pp oxi- m y 0 m. n o opi vi wing mo o g w wo n. ov ™ w o i ig n n qui i ion w on . u j p o m on i ion o mi i iz m v wi imi o vi u oom n g ping (g u ogni ion) niqu (ig.). i in p p iv w w up impo on vi u w . o o y oom i umin ion w p ow in o o in on w n i p y n imm i u oun ing . u ing moving g w in o u in vi u oom w y m o ion u wi n om j o y in 5° on . omp ion im w o i .

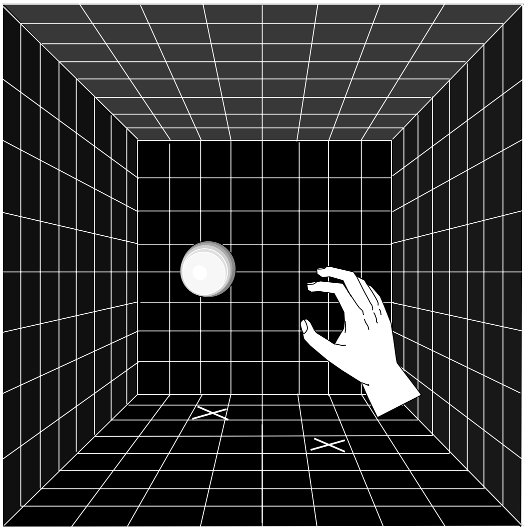

Fig. 3. xp im n vi u nvi onm n

wo g oup o 2 u j (2 m n 2 m) w u o xp im n . g oup p o m ing u ing mono opi i p y w i on g oup p o m m u ing o opi i p y. g oup w ivi in u g oup (1 o) o 7 u j . 1 p i p u ing g m 1 2 p 2 2 1 p 3 3 7 p 3 p n 5 5 2 p 1 p .

3 Results

omp ion im w u m u o p o m n . o v u o g p i up w o omp ion ov i n ov u j o o vi wing on i ion (mono opi n o opi). i ow omp i on w n vi wing on i ion o up n o i . u ow p o m n w om 2 p own o 1 p w n u ing mono opi vi u i p y (ig. 5) n om 2 own o 7 p w n u ing o opi i p y. o m n i no i i y i n w n 2 p n 1 o o vi wing on i ion (ig.). ow v o mo in- p o m n y 50% o up ow n 7 p . o pp o mo p ovi mo i u (50% m o up- w n 1 p n 7 p n 30% m o up w n 2 p n 7 p). o v ning p o op 9 i o up o mono opi vi wing (ig. 7). o o opi i p y i v y i ning o up ov 7 p . o ow up ning p o on inu up o 10 i (ig.).

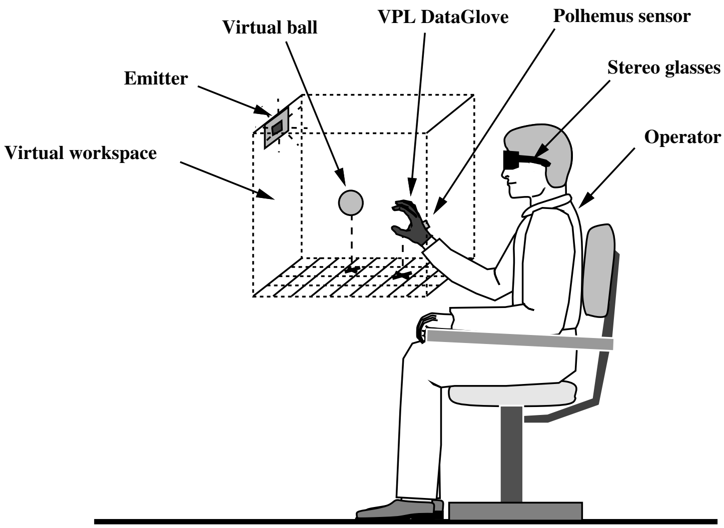

Fig. 4. xp im n on gu ion.

4 Discussion

o v o up qu o ig n 1 p u j mov i n on inuou y in p w i o up n o qu o 3 p y x i mov m n o o vi wing on i ion . n gy u w o mov n om po i ion o po i- ion. i ugg p io- mpo in po ion w impo i o p o m. Mo qui o m ximum up m po i p io- mpo in po ion o 3 moving g .

o opi vi wing p ov up io o mono opi vi wing o ow up . on i p o y o ow up op o w p ovi wi i o p i n i im g n p p i mo ion o - g on i g oun . u p in o m ion i y v i oug mo ion o o j in vi u n w no v i in i .

u on m o p viou y o in y g n n v y w o o v mo u p ju gm n wi yn mi i p i y ow 2 p . o up p io- mpo in po ion ow u o o j mo ion o p p p ion.

u o in om i xp im n ou omp m n y - ing in o on i ion p i u on i ion w o invo ving g ping g u o p o m wi omp i mov m n . ow v ou - u n u gui in o inv ig ion n ign o imp m nu in ion wi vi u o j .

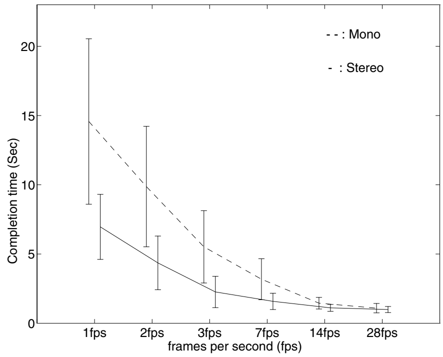

Fig. 5. M n omp ion im n n vi ion o o mono opi n o opi vi wing

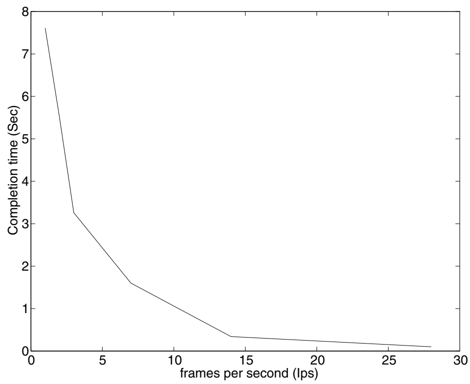

Fig. 6. i n o omp ion im w n mono opi n o opi vi wing mo v u m

5 Further Work

o x u iv u y o o m n vi wing on i ion on m n-u in ion wi vi u moving o j w omm n y n n mov m n o op o ou m u n in u in n y i o op o p o m n .

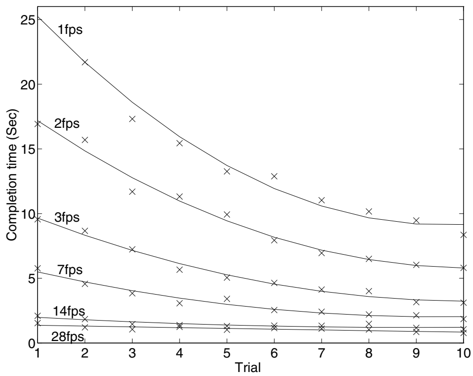

Fig. 7. *Mean task completion time versus trials using monoscopic viewing*

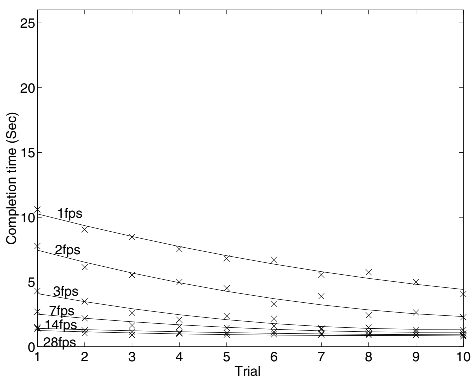

Fig. 8. *Mean task completion time versus trials using stereoscopic viewing*

6 Conclusion

v inv ig o o opi vi wing on um n ing/g - ping mov m n ow 3 moving vi u o j o i n g p i m . o m n w oun no o i i y i n w n 2 p n 1 p o mono opi n o opi vi wing. ow v o opi vi wing in p o m n y 50% o m ow n 7 p . i ugg o opi i p y mo u u ow m .

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Interactive Movie: A Virtual World with Narratives

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Abstract. t r ti o i s r s t o i t t i l ts i t r tio iliti s i to o i s. i t r ti o i s o l t r rs jo t lo t o stor i t r ti it r t rs i t stor . t is r rst l i t o t o i t r ti o i s ri fl s ri t rotot s st lo . t s ri t o str tio o s o s s t i r rr tl lo i s ll s s r l i ro ts i or or t i it.

1 Introduction

v sin th Lumi oth s t in m tog phy t th n o th 19th ntu y 1 motion pi tu s h v un gon v ious v n s in oth t hnology n ont nt o y motion pi tu s o movi s h v st lish th ms lv s s omposit t o m th t s v s wi ng o ultu l n s xt n ing om n t to m ss nt t inm nt ow v onv ntion l movi s unlit lly p s nt p t min s n s n sto y s ttings so u i n s t k no p t in th m n m k no hoi s in sto y v lopm nt On th oth h n th us o int tion t hnology m k s it possi l o th vi w to " om " th m in h t in movi n njoy st h n xp i n li v th t this pp o h woul llow p o u s to xplo th possi iliti s o n w l ss o movi s om this vi wpoint w h v n on u ting s h on int tiv movi p o u tion y pplying int tion t hnology to onv ntion l movi m king t hniqu s s n initi l st p in ting n w typ o movi w h v p o u p ototyp syst m 2 s on this syst m w u ntly v loping s on p ototyp syst m with m ny imp ov m nts his p p i fly s i s th st p ototyp syst m n outlin s its p o l m s n qui imp ov m nts h p p lso int o u s th on gu tion o th s on p ototyp syst m whi h is now ing n y in o po ting th s i imp ov m nts

J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 107–116, 1998.

2 Outline of Interactive Movies

2.1 Concept

Compared with existing media, interactive movies can be regarded as audience-participation, experience-simulating movies. An interactive movie consists of the following elements:

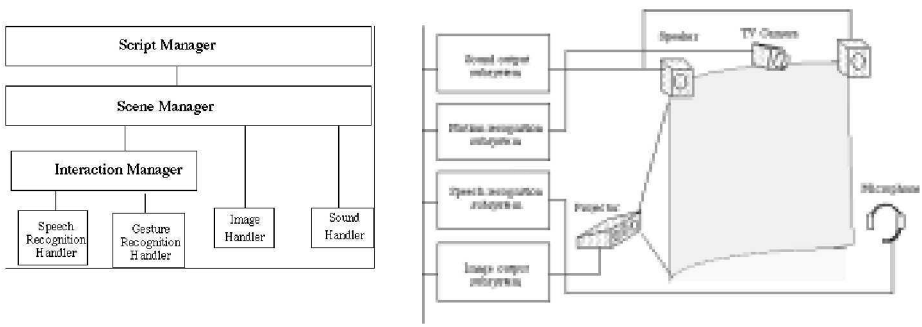
1. An interactive story that develops differently depending on the interaction of the audience;
2. An audience that becomes the main character and experiences the world created by the interactive story;
3. Characters who interact with the main character (audience) in the story.

2.2 Configuration of the First Prototype System

Based on the concept described above, we developed our first prototype system[2]. The following is a brief outline of this system.

(1) Software

Figure 1(a) shows the software configuration of the system. The interactive story consists of a collection of various scenes and a state-transition network between the scenes.



(a) (b)

Fig. 1. Configuration of first prototype system: (a) software and (b) hardware.

The script manager stores the data of the state-transition networks and controls the scene transition according to the interaction result. The scene manager contains descriptive data of individual scenes and generates each scene by referring to the descriptive data of the scene specified by the script manager. The interaction manager is under the control of the script manager and scene manager, and it manages the interaction in each scene. The handlers are controlled

y th s n m n g n int tion m n g h y ont ol v ious input n output un tions su h s sp h ognition g stu ognition output o visu l im g s n output o soun s

(2) Hardware

igu 1( ) shows th h w on gu tion h syst m onsists o n im g output su syst m sp h ognition su syst m g stu ognition su syst m n soun output su syst m n th im g output su syst m high sp g n ting wo kst tion is us o th visu l im g output h sp h ognition op tions x ut y singl wo kst tion h g stu ognition un tion is lso x ut y wo kst tion h soun output su syst m onsists o s v l s kg oun musi soun ff ts n h t i logs simult n ously p o u y this su syst m

2.3 Evaluation and Problems

t st th st p ototyp syst m with pp oxim t ly 0 p opl u ing th h l y p io ollowing ompl tion o syst m v lopm nt s on th i omm nts w v lu t th syst m n i nti s o u th s h s summ iz low

(1) Number of participants

h si on pt o th st syst m w s sto y with just on pl y ting th ol o h o ow v th st syst m l k th multi us un tions n o th sto y to t k pl in y sp sin y sp will t ov n two k n will qui th sto y to v lop om not just on pl y ut om th int tions o s v l pl y s p ti ip ting t th s m tim

(2) Frequency of interaction

nt tion in th st syst m w s g n lly limit to h ng points in th sto y so th sto y p og ss lin ly long p t min ou s lik movi x pt t th s h ng points h t in v nt g s to this t hniqu su h s ing l to us th sto y v lopm nt t hniqu s n xp tis u mul t y skill in m tog ph s ow v th is v nt g o using x sto y l m nts t in th s m w y s o onv ntion l movi is th t th pl y s ms to n up sp t to who n s it i ult to p ti ip t int tiv ly t points wh int tion is l ly qui h limit oppo tuniti s o int tion t oth w ks o th pl y su h s h ving littl to is tinguish th xp i n om w t hing movi n h ving v y limit s ns o involv m nt

3 Description of Second System

3.1 Improvement

h ollowing points w us to imp ov th s on syst m s s i low

(1) System for multiple players

Ou initi l ffo t to v lop syst m o multipl pl y s llow two pl y s to p ti ip t in y sp in th v lopm nt o sto y h ultim t go l

w s to t multi pl y syst m op ting oss n two k ut th st st p in th p s nt stu y w s th v lopm nt o p ototyp multi pl y syst m onsisting o two syst ms onn t y L

(2) Introduction of interaction at any time

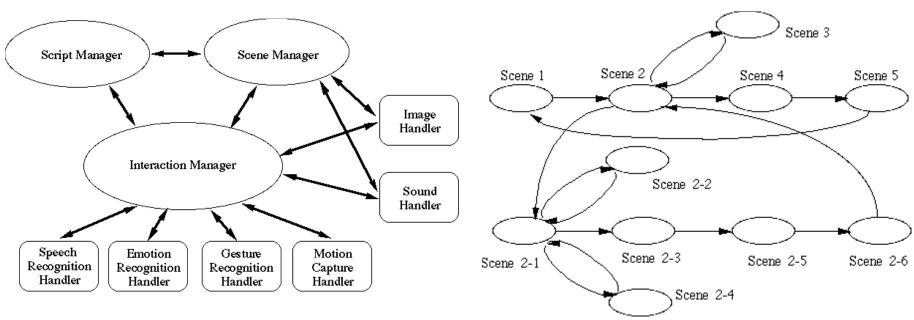
o in s th qu n y o int tion tw n th p ti ip nts n th syst m w vis w y o pl y s to int t with y sp si nts t ny point in tim si lly th s imp omptu int tions ll sto y un ons ious int tion ( ) o u tw n th pl y s n h t s n g n lly o not ff t sto y v lopm nt On th oth h n th som tim s int tions th t o ff t sto y v lopm nt his kin o int tion ll sto y ons ious int tion ( ) o u s t n h points in th sto y n th sults o su h n int tions t min th utu v lopm nt o th sto y

(3) Other improvements

motion ognition o liz int tion t ny tim n motion og nition p ility w s int o u h n pl y s utt spont n ous utt n s th h t s t y using th i own utt n s n nim tions o ing to th motion ognition sult Motion ptu int o u motion p tu syst m s on m gn ti s nso s h two m jo sons o su h syst m On is to show v t s s lt gos o th pl y s on s n thus giving th pl y s th ling th t th y lly tiv p ti ip nts with th syst m h oth is to imp ov g stu ognition h st syst m s g stu ognition s on im g s o t in y m w s in ff tiv u to low light h o w w nt to us motion ptu t o g stu ognition

3.2 Software System Structure

igu 2( ) shows th st u tu o th so tw us in th s on syst m



(a) (b)

Fig. 2. ( ) o tw on gu tion o s on syst m n ( ) s n t nsition n two k

(1) System structure concept

hil th st syst m st ss sto y v lopm nt th s on syst m h to hi v goo l n tw n sto y v lopm nt n imp omptu int tion y in o po ting th on pt o int tion t ny tim his qui uil ing ist i ut ont ol syst m inst o top own syst m st u tu

h is v i ty o hit tu s v il l o ist i ut ont ol syst ms ut w hos to us n tion s l tion n two k 3 th t s n s n iv s tiv tion l v ls mong multipl no s h s l v ls tiv t no s n t ig g p o ss s sso i t with th no s t point yon th tiv tion l v l th shol

(2) Script manager

h ol o th s ipt m n g is to ont ol t nsitions tw n s n s just s it i with th st syst m n int tiv sto y onsists o v ious kin s o s n s n t nsitions mong s n s h un tions o th s ipt m n g to n th l m nts o h s n n to ont ol s n t nsitions s on n in nit utom ton (ig 2( )) h t nsition om singl s n to on o s v l possi l su s qu nt s n s is i s on th sult s nt om th s n m n g

(3) Scene manager

h s n m n g ont ols th s n s ipt s w ll s th p og ss o th sto y in s n tion l t to th p og ss o th sto y in s n is ll n v nt n v nt t nsitions ont oll y th s n m n g v nts o h s n onsist o s n im g s kg oun musi soun ff ts h t nim tion n h t sp h n pl y n h t int tion

h s ipt o h s n is p sto h o tim in n v nt n two k n th s n m n g g n t s h s n s on t om th s ipt m n g vi s ipt

h timing o t nsition om on v nt to th n xt w s ont oll y th s n m n g in th st syst m ut solut tim nnot ont oll in th s on syst m us it in o po t s th on pt o int tion t ny tim ow v l tiv tim n tim o n ont oll in th s on syst m so th tion s l tion n two k w s ppli h s w ll h ollowing s i s how this wo ks

1 tiv tion l v ls s nt o x h ng mong v nts s w ll s xt n l v nts
2 n v nt tiv t s wh n th umul tiv tiv tion l v l x s th th sh ol
3 On tiv tion o n v nt p t min tion o spon ing to th v nt o u s t th s m tim tiv tion l v ls s nt to oth v nts n th tiv tion l v l o th tiv ting v nt is s t h o o v nts n p s t n v i tion s w ll s m iguity n int o u into th o o v nts y p t mining th i tion th t tiv tion l v ls s nt n th st ngth o tiv tion l v ls

(4) Interaction manager

h int tion m n g is th most iti l ompon nt o hi ving int tion t ny tim igu 3 shows th st u tu o th int tion m n g h sis o int tion t ny tim is st u tu th t llots h h t (in lu ing th pl y s v t) n motion l st t n int tion input om th pl y long with int tion tw n th h t s t min th motion l st t s w ll s th spons to th t motion l st t o h h t om l w y is giv n to how spons is xp ss p n ing on th h t s p son lity n i umst n s h int tion m n g is sign s on th on pts outlin low

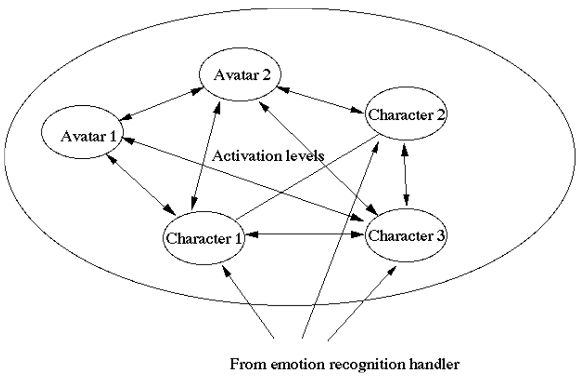


Fig. 3. t u tu o int tion m n g

1) ning n motion l st t

h st t n int nsity o pl y s (i 1, 2...) motion t tim T is n s

$$Ep(i,T),\ sp(i,T) \tag{1}$$

wh $sp(i,T)$ 0 o 1 (0 in i t s no input n 1 in i t s n input) imil ly th st t n int nsity o n o j t s (i 1, 2...) motion t tim T is n s

$$Eo(i,T),\ so(i,T). \tag{2}$$

2) ning th motion l st t o n o j t

o th s k o simpli ity th motion l st t o n o j t is t min y th motion l st t wh n pl y int tion sults om motion ognition

$$\{Ep(i,T)\} \rightarrow \{Eo(j,T \quad 1)\}. \tag{3}$$

tiv tion l v ls s nt to h o j t wh n motion ognition sults input s

$$sp(i,T) \rightarrow sp(i,j,T), \tag{4}$$

wh $sp(i,j,T)$ is th tiv tion l v l s nt to o j t j wh n th motion o pl y i is ogniz h tiv tion l v l o o j t j is th tot l o ll tiv tion l v ls iv y th o j t

$$so(j,T \quad 1) \quad \sum sp(i,j,T). \qquad (\ )$$

3) xhi iting tion

n o j t th t x s th tiv tion th shol p o ms tion $Ao(i,T)$ s on n motion l st t Mo sp i lly tion is h t s mov m nt n sp h s tion to th motion l st t o th pl y t th s m tim tiv tion l v ls $so(i,j,T)$ s nt to oth o j ts

$$\begin{array}{l} if\ so(i,T) > THi \\ then\ Eo(i,T) \rightarrow Ao(i,T),\ Eo(i,T) \rightarrow so(i,j,T) \\ so(j,T \quad 1) \quad \sum so(i,j,T). \end{array} \qquad (\ )$$

his m h nism t s int tion tw n o j ts n n l s mo iv s int tion th n simpl int tion with on to on o spon n tw n motion ognition sults n o j t tions

3.3 Hardware System Structure

igu 4 shows th s on syst m s h w st u tu ompos o im g out put voi n motion ognition g stu ognition n soun output su syst ms

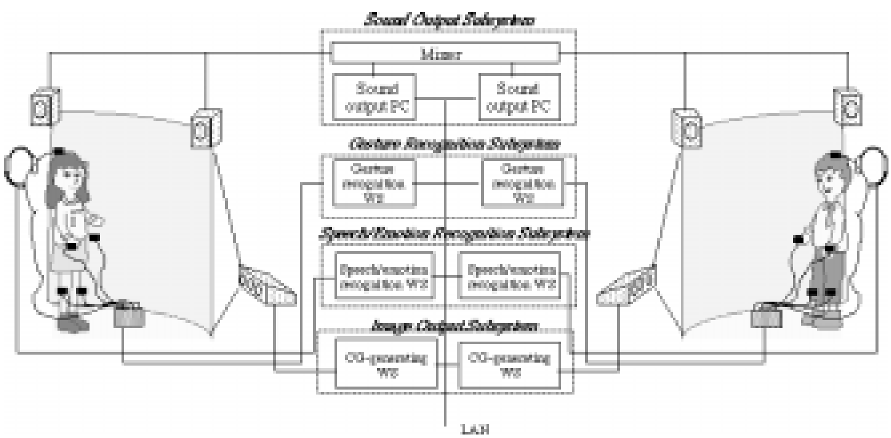


Fig. 4. w on gu tion o s on syst m

(1) Image output subsystem

wo wo kst tions (Onyx n nit lity n n igo 2 mp t) p l o g n ting omput g phi s t high sp us to output im g s h Onyx wo kst tion is us to un th s ipt m n g s n m n g int tion m n g n ll im g output so tw h t im g s p sto on th wo kst tions in th o m o omput g phi nim tion t in o to g n t omput g phi s in l tim kg oun omput g phi im g s lso sto s igit l t so kg oun im g s n g n t in l tim om kg oun im g s photog phi im g s o l s n y sto on n xt n l l s is h multipl h t omput g phi s kg oun omput g phi s n kg oun photog phi im g s p o ss simult n ously th ough vi o o s on oth th Onyx n n igo 2 wo kst tions

omput g phi s ispl y in 3 o mo listi im g s n u v s n is us to nv lop th pl y with im g s n imm s him o h in th int tiv movi wo l m g t o th l t n ight y p viously t on th wo kst tions int g t y st os opi vision ont ol n p oj t onto u v s n y two p oj to s On th n igo 2 n how v im g s output on n o in y l g s n ispl y without st os opi vision us o p o ssing sp

(2) Voice and emotion recognition subsystem

oi n motion ogniz with two wo kst tions (un 20s) th t lso un th voi n motion ognition h n l s oi input vi mi ophon is onv t om n log to igit l y th soun o uilt into th un wo kst tion n ognition so tw on th wo kst tion is us to ogniz voi s n motions o th ognition o m ning sp k in p n nt sp h og nition lgo ithm s on MM is opt 4 motion ognition is hi v y using n u l n two k s lgo ithm h wo kst tion p o ss s voi input om on pl y

(3) Gesture recognition subsystem

stu s ogniz with two n y wo kst tions th t un th g s tu ognition h n l s h wo kst tion t k s output om m gn ti s nso s tt h to pl y n us s th t t output o oth ont olling th v t n ognizing g stu s

(4) Sound output subsystem

h soun output su syst m us s s v l p son l omput s us k g oun musi soun ff ts n sp h o h h t must output si mult n ously oun ff ts n h t sp h sto s igit l t th t onv t om igit l to n log s n n multipl p son l omput s us to n l simult n ous igit l to n log onv sion o multipl h nn ls in o to output th s soun s simult n ously kg oun musi is sto on n xt n l omp t is whos output is lso ont oll y th p son l om put h multipl h nn l soun outputs mix n output with mix (m h 02) th t n ont oll y omput

4 Example of Interactive Story Production

4.1 An Interactive Story

h v p o u n int tiv sto y s on th p viously s i on yst m s l t " om o n uli t" y h k sp s th s sto y o th ollowing sons

1 h two m in h t s in th sto y n th o this suppli s goo x mpl o multi p son p ti ip tion
2 " om o n uli t" is v y w ll known sto y n p opl h v st ong si to t out th ol o h o o h oin h o it is xp t th t p opl n sily g t involv in th movi wo l n xp i n th sto y

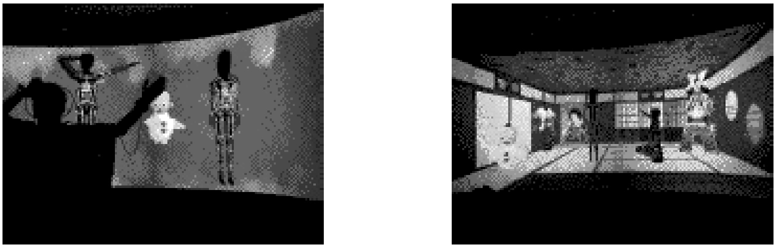
h m in plot o th sto y is s ollows t th i t gi sui i th lov s souls s nt to s wh th y n th t th y h v tot lly lost th i m mo y h n th y st t th i jou n y to is ov who th y n wh t th i l tionship is ith v ious kin s o xp i n s n with th h lp n gui n o h t s in s th y g u lly n th ms lv s g in n n lly go k to th l wo l

4.2 Interaction

h two p ti ip nts on pl ys th ol o om o n th oth uli t h two su syst ms lo t in two s p t ooms n onn t y L h p ti ip nt st n s in ont o th s n o his h sp tiv syst m w ing sp i lly sign loth s to whi h m gn ti s nso s n mi ophon s tt h n th s o om o th p ti ip nt w s 3 L shutt gl ss n n njoy 3 s n s h i v t s on th s n n mov o ing to th i tions h y n lso ommuni t y voi si lly th syst m ont ols th p og ss o th sto y with h t nim tions n h t i logu s p n ing on th voi n g stu tions o th p ti ip nts th sto y mov s on u th mo s is s i o int tion is possi l t ny tim h n th p ti ip nts utt th h t s t o ing to th motion ognition sults ons qu ntly p n ing on th qu n y o th p ti ip nts int tion this syst m n go nywh tw n sto y omin nt op tion n imp omptu int tion omin nt op tion igu illust t s typi l int tions tw n th p ti ip nts n th syst m

5 Conclusions

n this p p w st xpl in th on pt o int tiv movi s n i fly xpl in ou st p ototyp syst m s on n v lu tion o this syst m w i nti s v l p o l ms in th syst m th t n to imp ov On is th l k o qu nt int tions n th oth is singl p son p ti ip tion o ov om th s i n i s w v loping s on syst m xpl in



(a) “Romeo” controls his avatar

(b) “Romeo” tries to touch object in Japanese curiosity shop

Fig. 5. x mpl s o int tion tw n p ti ip nts n syst m

two signi nt imp ov m nts in o po t into th s on syst m int tion t ny tim n two p son p ti ip tion th ough n two k s i th so tw n h w on gu tions o th s on syst m whil mph sizing th s imp ov m nts in lly w illust t th op tion o ou on yst m with th x mpl o ou int tiv p o u tion o ” om o n uli t”

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Real-Image-Based Virtual Studio

ong l k n iki nou

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Abstract. In this paper, we propose a real-image-based virtual studio system where a virtual environment is generated by an image-based rendering technique and then a studio scene is put in the environment based on a 3D compositing technique. The system is implemented and the validity of the system is confirmed through experiments.

1 Introduction

o on u ing n i pl ying vi u l nvi on n n x n iv ly xplo o in o n o i l l .
k y nology in i o o po i v iou i g vi o ou in o n i g vi o. n on i l wo k on jux po ing l i g n o pu g p i ( ) in on x o vi u l li y. K u g ' L 4 o u on in ion w n u n o pu g n wo l . y i *et al.*' vi u l u io y 1 p iz i g qu li y. i n o o i pu po . o i i ing p ovi ing u wi in iv ly njoying vi u l wo l w il l i pu uing ig qu li y in g ion o ul ipl i g ou in vi u l wo l . n o o n w o o o n in ion wi vi u l nvi on n n g n ion o ul i i on n w v loping n g xp ion oo (oo) 2 . n oo on n lo n o v on l in vi u l nvi on n n n v iou i g ily wi ig g o o .

n i p p w o u on pu uing li y in vi u l wo l . i i o ul i i on n . y on u ing n i pl ying vi u l nvi on n n n in ing u io n in nvi on n w g l u io n n vi u l nvi on n . vi u l nvi on n n l i g w ll . i in lu only ging i o i pl . u ing p o o o o l king u io n woul noug . i i pp o k n in 1 . w on i o o i g ou .

p opo l i g vi o o po i ing y *Real-Image-Based Virtual Studio* in i p p . o n ing u o y y

J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 117–122, 1998.

o g n n i y vi w u ing l i g u vi wpoin o i n ion n on i ion o vi u l king vi u liz l n vi on n oul ju o o o u io . n i g n ing niqu i ploy o qui n .

pp o in i p p i o k n nvi on n n wi ul ipl n n o x p n n p p on ul i vi w o ing nology . n n i y vi w i g n u ing i g n p p . in p p o i y vi w i i ul n ou ly g n o i w ll ui o Z k y o po i ion. n i pl y g i g on l g n in on o oo n in ily wi vi u l nvi on n w i n l n u l i g xp ion.

2 Image Expression Room

i fly in o u on p o oo . igu 1 ow i on g u ion.

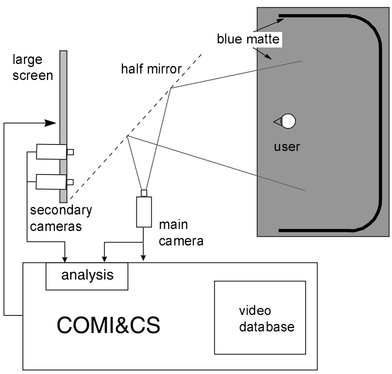

Fig. 1. g xp ion oo .

jo o pon n o oo in lu o k y u io l g n l i o in on o n u io n (o pu g niz i n g ion n o uni ion y). u n i l l in vi u l n n xp i l l wi in ing i oug . in oo u io n oug l i o o i o n. n i w y u n in wi ou pu i g i i ing i o w i i on o o onv ni n n i n ly w y o in ion o u n. u o y on w n o n vi w n liz wi in g zing on l l o i pli g zing u vi w in on gu ion o oo . lu kg oun gion in i g o in i li in y

p ing oug o k y . on y n u n o ion n y n ly o on ol v iou i o pon n . il n oun in 2 .

3 Real-Image-Based Virtual Studio

3.1 3D Virtual Environments

n i g n ing niqu i ploy o ing vi u l nvi on n . p o uil vi u l nvi on n u ing ul i vi w l i g n i i p i y p. iv u in ou i pl n ion. n i lo n n o lo y i lly in o izon l n v i l i ion. n n p p p o n i x on i o ul i vi w o ing niqu w i i ign o ov o o o lu ion . w n g n n i y vi w only u ing v il l in o ion ul i vi w i g n p p w n y l n i vi u liz . n i w y w n on u vi u l nvi on n .

3.2 Arbitrary View Generation

g n n i y vi w n i p p giv n ul i vi w i g n n i g ' p p. o i on 2 p pp o . up po w v vi u l n ov o n i y po i ion n o i n ion.

i p i o op wi pu n l ion o vi wpoin . i p o p n on p o pix l. u w ll i 3 p o ing. i p on i o n o ing p p in o o n w vi w po i ion n n pping o olo o i g o p op on y .

p p o n vi w i n o in o o n w vi w po i ion. o w pping niqu wi up pling i u . o ol w ul ipl pix l pp on g i w oo ll ong up po p v lu u ing o j op qu . olo (o in n i y o g y i g) in o ion i i ul n ou ly pp u ing n o ion. o un ov w i ion lly in pol p p. k u o kg oun p v lu in in pol ing p o un ov . on o in pol p p o un ov i wo ol . n i o p ovi w y o gu ing p op olo in o ion o on y . o i o ou pu p p o u u in 3 vi o o po i ion. n w in pol olo o un ov y k pping u ing p v lu n v li i y k.

on p i o op wi zoo ing n pu o ion o vi u l . i in p n n o p o pix l n u involv only 2 p o ing. No i w n w n l o i n ion n l w l o o jo o p p o p p o 3 o po i ion.

il on i y vi w g n ion n oun in .

3.3 3D Video Composition

vi o o po i ion in oo n ivi in o 3 go i on l v l o xploi ing 3 p op y. n i 2 o po i ion w ul ipl i g ou ju jux po in l y . on i 2.x o po i ion on l y p n ion o i g qu n 9 w i i yon 2 u low 3 . g n i g in o o l y n n l l y in p n n ly. i i 3 o po i ion on ull 3 in o ion o n w i w o u on in i p p .

uppo w o g ul ipl i g ou in o on i g . ll i g ou k n y x vi o w n g i g y i pl Z k y o 3 . i p i y v lu o pix l o ul ipl i g o o po o p n i g o l g i p i y quiv l n ly n poin o pix l po i ion l pix l v lu o o po i g .

on o un go wo k w oul ju o i g o ing o wo k 1 . n oo in i llow o ov ly n o ng o l l ng . u w n w o pu u io n in vi u l nvi on n vi u l oo ing vi u l nvi on n oul l o v y o ing o wo k o in . o ov o u iliz Z k y o o pon ing p p oul l o p p . n i pl n w i in .3.2.

3.4 Implementation

ov ll lo k i g o l i g vi u l u io y in oo i own in ig.2

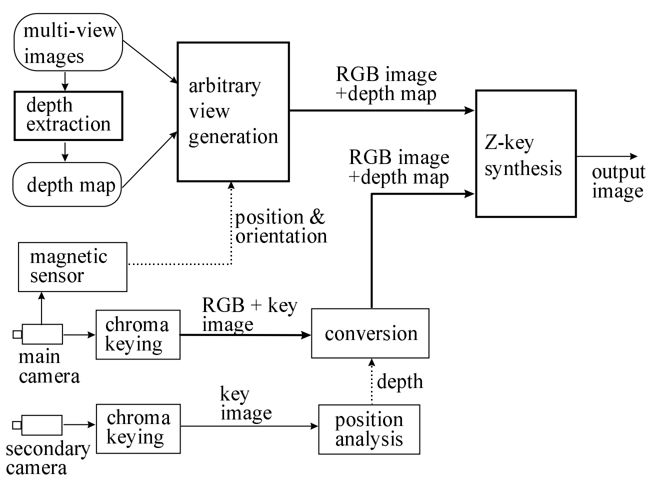

Fig. 2. on p u l flow i g o l i g vi u l u io y in oo .

po i ion n o i n ion o in u y gn i n o n n i o i y vi w g n ing uni . vi w g n ing uni p o u vi u l vi w ving po i ion n o i n ion o o o in . u vi w g n ion i pu ly o w i pl n now i nno p o u i y vi w in vi o . u w p p n i y vi w n i p p *a priori* o nu o pl vi w poin wi in volu o in n o in o y i il o pp o o ovi p 5 . n w w n o xplo vi u l nvi on n in o wo w n w o g u io n in vi u l nvi on n n vi u l vi w po i ion o u v lu l ul . n o pon ing vi w n i p p ll o o y n n i o *Z* k y yn i uni oug g o i l n o ion uni . g o i l n o ion uni x u 3 i g o ion n zoo ing in l i . n i i pl n ion yn i vi u l nvi on n i. . on ining oving o j nno n l . o i l olu ion ow yn i nvi on n y o k i y vi w g n ion p o in vi o w i i un x n iv inv ig ion.

po i ion o u on lu kg oun u io i y on y lo on op o n. p io i knowl g u i on fl floo i xploi . i g o in i now n o in o n i g wi on n p u y on y n n i o *Z* k y yn i uni . in i g o in i g fl p n l p i p u 3 o po i ion i no llow in u n i pl n ion. n i v only i w v l i n p pp in u io 3 . n o ppli ion ow v fl p n l pp o giv u i n ly goo ul . no li i ion u n i pl n ion i ul i o n l in on l y . o n l p ly w oul in o u n n ly i uni po i ly wi o on y w i i u n ly inv ig . ing l i n p pp n l o olu ion.

ow xp i n l ul in ig.3. u i n ing x po i ion. in i ov iv ly o ig (u lly o l u w u l i o in oo) n lig ly zoo ing in. qui n u l looking o po i ion ul . n w o v n in l i w l u w u lly in vi u l nvi on n . v on oug ny xp i n vi w yn i o oul g n v i y o l i g vi u l nvi on n u ully n 3 o po i ion wi oving oul p o u n u l looking o po i ion i g .

4 Concluding Remarks

n i p p w p opo l i g vi u l u io y w vi u l nvi on n i g n y n i g n ing niqu n u io n i pu in nvi on n on 3 o po i ion niqu .

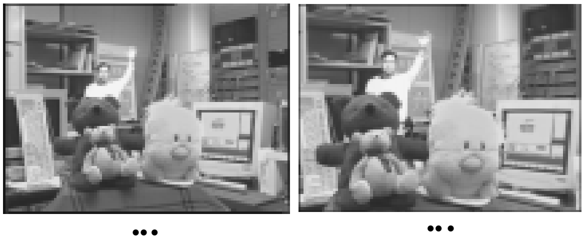

Fig. 3. xp i n l ul 3 o po i g ( ) o n ( ) op ion.

p o o yp y i i pl n n v li i y o y i on oug xp i n .

u n i pl n ion yn i vi u l nvi on n nno n l . u u o i x on g n ing i y vi w in l i . no li i ion i ull 3 in o ion on o j in u io i no v il l w i n ov o only y in o u ing l i n p pp .

l o on i ing no n io in vi u l u io king n y oving i ing u ing o ion n n on ol u io o ing o i u o ion.

Acknowledgment: u o g ul o . ki y i o N K o i v lu l o n .

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Pop-Out Videos

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Abstract. This paper discusses a class of multimedia displays that we call *pop-out videos*. A pop-out video is a composition of multiple elementary displays. Some of these base elements are video streams, and some are three-dimensional graphic displays. The elementary displays of a pop-out video may be related in two ways. They may be contiguous portions of a single virtual world, forming what we call an *integrated video space*. Alternatively, they may be parts of distinct spaces, forming what we call a *complementary video space*. In both cases, the elementary displays are related to each other by coordinated event handling. In our on-going research, we are using pop-out videos to create multimedia virtual worlds and to orchestrate the presentation of data in multiple media. After a survey of related work, the paper outlines our initial implementations of pop-out videos and presents future plans.

1 Introduction

We are building *pop-out videos*. These are multimedia displays that combine video streams and three-dimensional graphic displays. The elementary displays of a pop-out video may be related in two ways. They may be contiguous portions of a single virtual world, forming what we call an *integrated video space*. Alternatively, they may be parts of distinct spaces, forming what we call a *complementary video space*. In both cases, the elementary displays are related to each other by coordinated event handling.

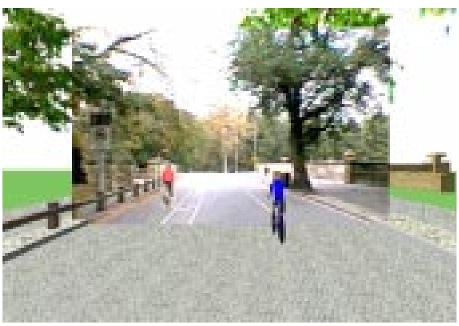


Fig. 1. Integrated Video Space

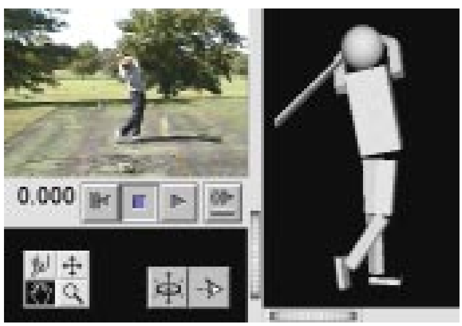


Fig. 2. Complementary Video Space

J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 123-128, 1998

Figure 1 shows an integrated video space created by Peloton [1]—a sports simulator that creates virtual courses for bicycle rides. The central portion of this view is a video stream, which is displayed as a texture on a large rectangle—a two-dimensional video "screen." In the surrounding display, three-dimensional graphic elements represent the road and some roadside objects. The bicyclist avatars represent multiple simulation participants. As they explore this virtual world, users move through the three-dimensional synthetic terrain and view photo-realistic scenery.

Figure 2 illustrates an example of a complementary video space. In this case, the video display and the graphical display are not composed into a single virtual world. Rather, these displays are related only by their integrated responses to system events. This golf instruction program helps students associate the techniques of good golfers with the motions of simpler graphical figures. Students watch video clips showing golfers—who have exemplary technique—swing clubs to hit balls; they also watch three-dimensional humanoid figures demonstrate corresponding animations. By viewing both presentations, students learn to monitor the most important elements of successful club swings.

In our current research, we are creating new techniques to build pop-out videos and to orchestrate the presentation of data in multiple media. We are learning more about how to design and assemble collections of multimedia displays, and we are investigating ways to use them.

2 Background

A variety of applications integrate three-dimensional graphics with still images or video clips. Photographs are commonly used as textures and background elements in three-dimensional virtual worlds. In addition, image based modeling techniques, *e.g.*, [2] and [3], permit creation of three-dimensional models from two-dimensional photographs. However, these applications do not represent three-dimensional spaces with video, and they do not permit objects to move between graphical regions and video regions in response to user input/output events.

Virtual sets, *e.g.*, [4], [5], also combine video and three-dimensional graphics. In [6], live actors can move within computer-generated settings. Augmented reality systems, *e.g.*, [7], demonstrate another combination of these media; they lay computer-generated graphics over video inputs. The Interspace system [8], which supports multiparty conferences on the Internet, creates virtual spaces in which avatars have live video streams as "heads." [9] discusses virtual reality systems, containing video displays, in which the relative importance of model elements (objects) is specified and used as a quality-of-service control for video transmission. These examples represent steps towards integrated video spaces; however, they do not use video for the representation of spaces within three-dimensional graphic models. Television and Web documents can be combined with WebTV devices [10]. However, these devices

do not create complementary video spaces because they do not provide any association between the television programming and the Web based materials.

The MPEG-4 standard proposal [11] is expected to allow specification of video graphical hybrid environments. Its video based objects might form an appropriate infrastructure for pop-out videos.

3 Integrated Video Spaces

An integrated video space represents some parts of a virtual world as three-dimensional objects and other parts of the same world as still images or video. Because these displays are parts of the same virtual world, we call them *regions* of the world. The size, shape, and position of each region is calibrated with its neighboring regions to create visual unity of the composite space. A common set of controls and integrated event handling mechanisms are associated with the single world. Objects can move from one part of an integrated video space to another. Hence, we must handle the movement of objects between graphical and video regions. We have developed two techniques to deal with these inter-regional object movements.

In the first technique, when an object moves from one region to another, the medium used to represent that object correspondingly changes. The new medium matches the one used to represent the other objects in the new region. For example, when an object goes from a three-dimensional region into a video-based one, it becomes a video element. We call this transform a *merge-in* because, in a sense, the object has "merged into" the video panel.

Figure 1 illustrates a world in which an avatar has moved from a graphical region into a video region and has become a video element. Figure 3 is a behind-the-scenes view of the same merge-in. On the far left, a semi-transparent avatar represents the red cyclist's "real" position in the virtual world. In conventional three-dimensional worlds, the video panel would occlude the yellow cyclist's view of the red cyclist's position. However, by performing the merge-in, Peloton allows the red cyclist to remain visible to the yellow cyclist. Using the red cyclist's real position, the animation system translates and scales the red cyclist's video panel for the yellow cyclist's view. Figures 5 shows a close-up from this point of view.

In our second technique, we permit objects to be designated as *traceable objects*. When a traceable object moves from a three-dimensional region to video panel, it does not become a video element. Instead, it is replaced in the three-dimensional foreground by a *trace object*. A trace object is an element of the foreground that represents an object "behind" the video panel. Figure 4 shows the same scene as Figure 3, but this time a trace object is used to maintain the red cyclist's visibility. The animation system translates, scales, and maintains orientation of the trace object

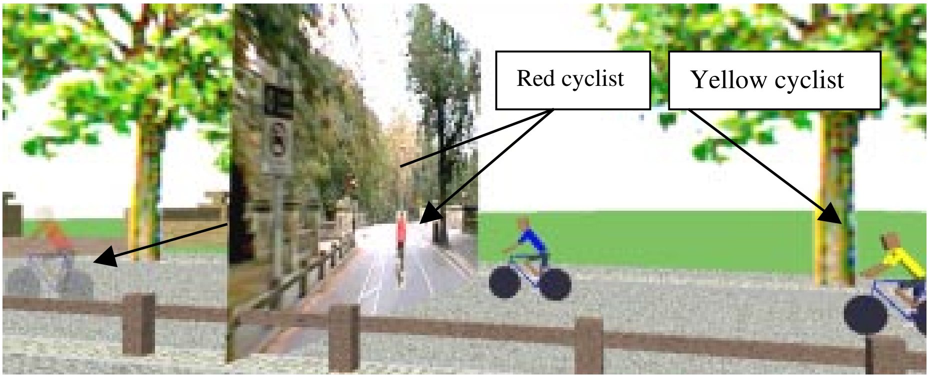


Fig. 3. Behind-the-Scenes View of a Merge-In

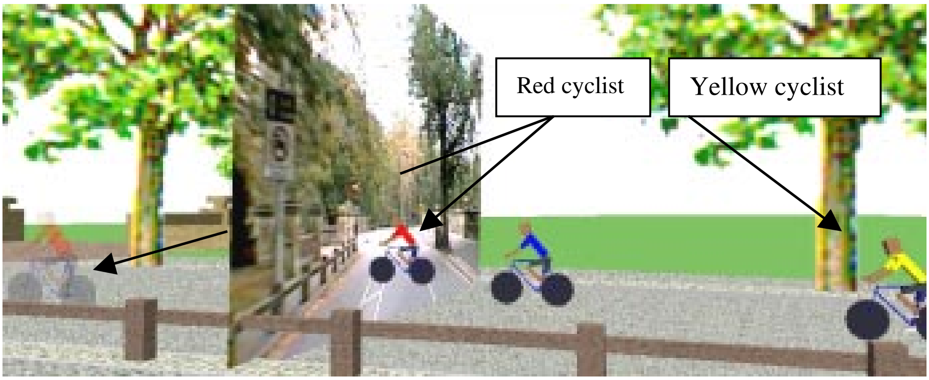
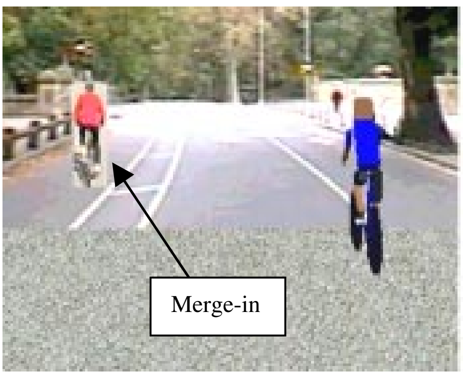


Fig. 4. Behind-the-Scenes View of a Trace



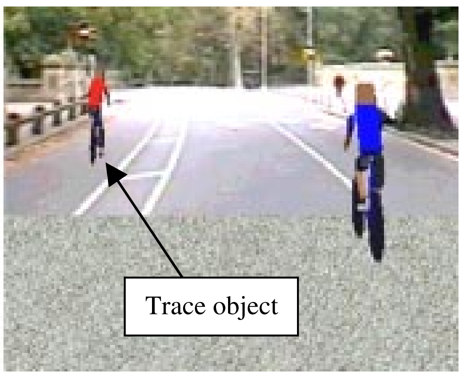


Fig. 5. Yellow's View of a Merge-In

Fig. 6. Yellow's View of a Trace

for the yellow cyclist's view, according to the red cyclist's real position. From the yellow cyclist's viewpoint, it is not possible to distinguish between the "real avatar" and the trace object. Figure 6 shows a close-up of the yellow cyclist's view of the scene.

4 Complementary Video Spaces

In this type of pop-out video, the video display does not integrate with other displays to form a single virtual world. Rather, the displays are related only through their coordinated response to the events that their common application handles. Without visual unity of a composite space, the common control interface and integrated event handling are created as distinct system components. Without regions for a common space, objects do not seamlessly move from one display to another. However, the elements represented in these regions are related through system actions.

In Figure 2, both regions display the same golfer but in different media. On the left-hand side, the golfer is represented as video, whereas on the right-hand side, it is represented as a three-dimensional humanoid. This configuration allows users to manipulate elements, *i.e.* the golfer, in one region and to see the effects in both regions. Multiple representations of data is not a new concept. What is new in complementary video spaces is the ability to associate manipulations in a graphical region to the ones in a video region (and vice-versa). For example, playing back the video stream of the golfer may trigger the animation of the humanoid. When the two regions respond "in synch," users experience the photo-realistic view of the video and also see the humanoid's swing from several viewpoints. Handling of events can also result in asynchronous responses.

To implement the environment described above, complementary video systems must provide users with a set of controls to perform the manipulations. Also, these systems must be able to "translate" the manipulations performed in one region to the corresponding ones in the other region.

5 Future Work and Conclusion

Pop-out videos provide apparent benefits in building virtual worlds as well as displaying information in multiple media. Shopping applications, similar to the golf program described above, could allow shoppers to pick objects from a video catalog or a commercial video and see them in other forms, or pick them from other regions and see them displayed in a video. Also, media melding techniques can be used within a multimedia virtual world to implement multimedia level-of-detail. For example, a surveillance application could display a region near the viewer (camera) in video, while displaying more distant areas through other media. Pop-out videos could enhance television programming by coupling video with information represented in other media. The closed caption (subtitle) concept of today's television allows text to be associated with video content. This concept can be extended to associate other information—displayed in other media—with video content. For example, hyper-textual Web documents and three-dimensional virtual worlds could be associated with video programming content. Various suppliers, including the producers of the

original programming content or specialized providers, could supply these additional materials. In fact, several collections of additional material could be available for each program. Consumers could then select their preferred collections.

Pop-out videos can also be used to build distributed virtual worlds that react to performance constraints. Since region boundaries within a virtual world can vary dynamically, the relative media mix of a world can vary correspondingly. This variation provides an opportunity to tailor applications and their presentation of information to the needs and resources of the system user. For example, it could improve the performance of a distributed application executing on heterogeneous computers connected via the Internet. Application users with powerful machines but poor network connections could take advantage of their computing power by specifying that a virtual world be presented mainly as three-dimensional objects rendered locally. On the other hand, users with network computers—offering high-end network connections but less processing power—could specify that the scene be presented using minimal three-dimensional representation to view most of the scene as streamed video.

Although many issues still need to be resolved, these examples show that the integration of video in richer multimedia environments could open the doors of a very large set of interactive multimedia applications.

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Color Segmentation and Color Correction Using Lighting and White Balance Shifts

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Abstract. A method was developed to segment an image foreground and background based on color content. This work presents an alternative to the standard blue-screen technique (weather man method) by exploiting the color shifts of light sources and filtering each camera lens and correcting white balances for each camera. we compressed the colors of the scene background into a chromaticity subspace to make the foreground-background segmentation easier to perform. The segmentation is singular decomposition (SVD) based.

Keywords: olor gm nt tion, lu r n, 3 ooting, irtu l lity, rom -k y

1 Introduction

ppli tions d m nding n utom ti vid o str m s gm nt tion r num rous n of t most f mous is t lu s r n w t r m n) m t od w r su j t situ t d in front of uniform lu w ll or y loid, is ov rl id on n ot r im g y n utom ti rom -k y s gm nt tion n t l vision produ tions, t lu s r n is us d in studio nvironm nt nd llows limit d possi l positions nd ori nt tions for t m r s n virtu l lity ppli tions su s t 1 , on w nts to s gm nt for ground su j t from kground s n using t p rsp tiv of n r itr rily position d nd ori nt t d m r , uilding 360 d gr s lu s r n is not usu lly f si l , s it would imply to p int n ntir sp r in lu , position t su j t insid nd provid ol s for m r l ns ddition lly, t lu s r n m t od r quir s p rti ul r tt ntion for s dows proj t d on t lu w ll nd t qu lity of t s gm nt tion d p nds on t uniformity of t lig t spr d on t kground

n our ppro , t lig ting of t kground is mor tol r nt T is l im is justi d us w do not v d rk surf s w i g n r t nois ur m t od is simpl to r li in pr ti , nd do sn't r quir ution on kground lig t- ing in t rms of uniformity nd s d s of illumin tion not r import nt im- prov m nt is t t som on n w r lu lot s nd still s gm nt d orr tly n d pt t s gm nt tion to t su j t nd t kground s n inst d

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of imposing onstr ints on t tors lot s nd kground olors T is provid s n w fl xi ility s ow t t our m t od ould xt nd d to st nd rd outdoor s ooting wit f w onstr ints w i ould m k it v ry us ful

T is work provid s t r import nt n ts t 1) provid s not r solution to t for ground- kground s gm nt tion pro l m y using lo l lig ting onditions to for s p r tion of olors in t rom ti ity olor su sp ; it 2) dis uss s t us of t w it l n nd xploits t r l tions ip tw n w it l n s ift nd t olor tint; nd 3) n lly provid s solution for orr ting wrong m r w it l n quir d in t d t tion 2 dis uss s t t ory nd d v lopm nt of t on pts us d to support t is work tion 3 ov rs t olor orr tion t niqu s tion 4 dis uss s n s d s gm nt tion nd olor lust ring m t od tion 5 d s ri s t xp rim nts w ondu t d nd provid s dis ussion nd on lusion of t r sults

2 Theory and Concept Development

nd rst nding t r sults w pr s nt r r quir s l r und rst nding of r li ing t olor s ift t roug lt ring nd s ifting of t m r w it l n n ddition, t p ysi s of t lig t sour s, t ppropri t lt rs, nd t ir imp t on t olor ompr ssion in t rom ti ity olor su -sp must und rstood in lly ll of t im g d t is quir d y m r , t r for , t pit-f lls of d t quisition using "off-t -s lf" nd " ro d st qu lity" m r s s ould lso xplor d

2.1 The Color Shift

nst d of s ooting su j t in front of sp i olor d kground, w ng t sp trum of t for ground lig t y pplying olor d lt r in front of t ul f w orr t t is s ift only for t for ground nd not for t kground w " ompr ss" t ntir kground in r gion of t olor sp T r r two w ys of doing t is

– Tuning t w it l n of t m r s) on t t mp r tur of olor of ll t ul s involv d in t s ooting usu lly 3200 K for indoor lig ts, w us d 650) dding lt r on t l ns of t m r , t is lt r is n opposit olor of t on position d on t for ground lig ts did two t sts in using som os o lt rs
  1 T st 1 ull lu #3202 oosts 3200 K to 5500K) on for ground lig ts nd os osun85 #3401 onv rts 5500K to 3200K) on t m r l ns
  2 T st2 lf lu #3204K oosts 3200 K to 4100K) on for ground lig ts nd os osun lf T #3408 onv rts 5500K to 3800K) on t m r l ns

  n t s xp rim nts, w us d lmost ompl m nt ry lt rs , t n us t is ompl tion is f r from p rf t t r sult of t orr tion will littl it tint d or ng not d sir d s ift t t w ould orr t y t olor orr tion m t od xpl in d furt r

– s ond m t od for doing t is, is to djust t m r w it l n to t lig t spr d y t for ground sour s ving t lf lu or full lu lt r on) T is m t od is us full only for orr ting sm ll s ifts ow v r, it giv s som tt r r sults

2.2 Light Sources

T lt rs w r not t uniqu olor s ifts tu lly t w it of qu l n rgy do sn't xit, ll t w it lig ts w n s r in f t mor or l ss tint d n pproxim tion of t sp trum of t w it lig ts ul s is giv n y t l n k's qu tion

$$) \quad {}_1 \quad {}^{-5} \quad {}_2 \quad - 1)^{-1} \quad {}^{-3} \qquad 1)$$

r $_1$ 3 7415 10-16 ^{2} nd $_2$ 1 4388 10-2 m K T is t t mp r tur of olor of t sour t olor of t sour is usu lly d s ri d y t quiv l nt l n ki n r di tor n our xp rim nts, t ul s d t mp r tur of olor of 3200K indoor lig ts) pplying som olor d lt rs to sour is quiv l nt to produ t of t lig t sp trum nd t sp tr l tr nsmission f tur s of t lt r igur 1 s ows t sp trum of t lig t spr d on t for ground v r l

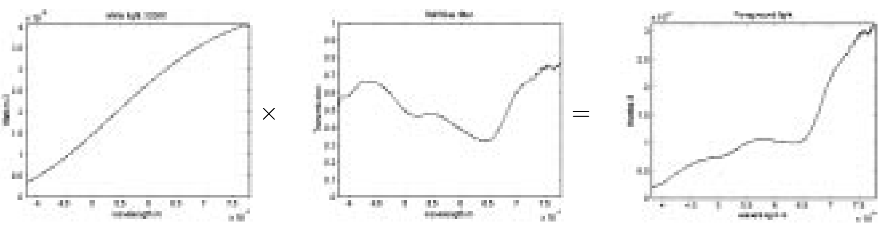

Fig. 1. sulting lig t sp trum from lf lu lt r dd d on 3200K w it lig t;)sp trum of t 3200K w it lig t f);) tr nsmission f tur s of t lf lu lt r g); nd) t r sulting for ground lig t sp trum f)g)

sp tr m y r t t s m stimulus, t is prin ipl is ll d "m t m rism" T is p nom n is wid ly us d in vid o to synt si sp i olor from only 3 r ys of olor d lig ts or x mpl onsid r t r d, gr n nd lu prim ri s f r n s 2 3 5 6 4 giv s good sis to st rt wit

not r r pr s nt tion of lig t sour p ssing t roug lt r would mixtur of only on r y of pur olor nd w it of quiv l nt n rgy r t tint is giv n y t w v l ngt of t r y, t s tur tion is giv n y t p r nt g of w it dd d to t is olor, nd t int nsity is giv n y t tot l n rgy of t is mixtur n ord r to o t in t is n w r pr s nt tion w i is si r to int rpr t, w n d to omput produ t of onvolution of t sp trum of stimulus nd t t r urv s of t s nsitivity of st nd rd um n vision syst m T s d n d s t of t r urv s $^{-}\ \bar{g}\ ^{-}$) or $^{-\ -\ -}$) 7 8 9 giving t s nsitivity of st nd rd " y " to sp i olor T us, w o t in

$$\begin{array}{l} \int \quad) \quad)^{-} \quad) \\ \int \quad) \quad)^{-} \quad) \\ \int \quad) \quad)^{-} \quad) \\ \dfrac{100}{\int \; (\;)^{-}(\;)d} \end{array} \qquad 2)$$

r is t illumin tion sour , is t sp tr l r fl t n f tor, nd , nd , r t tristimulus v lu s in t r pr s nt tion n now r pr s nt t stimulus in t rom ti ity di gr m x,y) n t x mpl low, w r studying ow s ift t lig t sour , t n w 'll onsid r t t on t ntir visi l sp trum

$$\frac{}{+\;+} \qquad \frac{}{+\;+} \qquad 1 - \quad - \qquad 3)$$

T igur 2 s ows ow to g t t tint of stimulus , y omputing t

Table 1. x,y oordin t s in t rom ti ity su sp of t lig ts nd lt rs

	Light 3200K	Light 3200K with a Half blue filter	Light 3200K with a Full blue filter
x	0.4234	0.3808	0.3387
y	0.3991	0.3806	0.3316

int rs tion of t lin joining t w it of qu l n rgy) nd t studi d olor) nd t ound ry of t urv s or t purpl olors, w i do

Fig. 2. nt rpr t tion of s ift d w it in t di gr m

not orr spond to uniqu r y of lig t, w will us − for d s ri ing t tint t is is tu lly t tint of t opposit olor) in t purity of x it tion s som int r sting g om tri prop rti s, w 'll us it l t r for t olor orr tion, ut t olorim tri purity is mor pr is , t is is t on will us r

$$\frac{}{} \qquad \frac{1 - \frac{}{}}{1 - \frac{}{}} \qquad 4)$$

r is t lumin n of t w it nd t lumin n of t pur olor on t ound ry of t di gr m or dding two stimuli w know lso t t

$$ {}^{w}_{w} \quad - \qquad\qquad {}^{w}_{w} \quad - \qquad\qquad 5) $$

T n, knowing t nd v lu s for , nd , w n r solv syst m of t r qu tions for d t rmining t lumin n v lu s nd t n t purity rom ti n m y oos 1 , sin w just n d to omput t r l tiv lumin n s

T n, stimulus m y r pr s nt d s n ddition of two stimuli p rt of rom ti lig t) nd p rt of pur olor lig t)

in w r only onsid ring t lig t sour t r fl tion is 100 on t ntir sp trum , t r sulting stimulus) is giv n y w will only do t proof for , sin nd r simil r)

$$ 1 - \;) \qquad\qquad 6) $$

T is int rpr t tion r pl s ny olor d stimulus y n ddition of n qu l n-rgy w it nd pur olor r y T s r l tions ips r v ry us ful for orr ting olor s ift

ur go l is to s gm nt utom ti lly su j t situ t d in t for ground of s n f w lig t t for ground wit lu lig t nd t kground wit 3200K lig t, t kground r quir s lig ting wit mor ”or ng lig t” t n t for ground T is ff t will s ift t olor of t kground tow rd t or ng y llowis r gion of t rom ti ity su sp f w orr t t for ground lig t t t m r t r sult will norm l for ground w il t kground g ts ompr ss d into s l t d r gion of t rom ti ity su sp

T rst w y of doing so is to tun t w it l n of t m r on 3200K nd lming t roug n or ng lt r ompl m nt ry to t lu lt r on t for ground lig ts f t lt rs r lly ompl m nt ry, t for ground lig t is p r iv d w it 3200K) nd t ntir kground is s ift d in or ng , it full lu lt rs on t for ground lig ts nd full or ng lt r on t m r l ns, t kground is s ift d of full or ng w il t for ground pp rs orr tly w it l n d n f t, in our xp rim nts t is orr tion is not p rf t us t lt rs w r not ” x tly” ompl m nt ry T r r no p rf t ompl m nt ry lt rs omm r i lly v il l t t is tim N xt w pr s nt w y of orr ting s ift d im g ft r ing s gm nt d

n mig t int r st d in s ifting t kground y mor t n on full or ng in ord r to p rform tt r s gm nt tion s d on olor t is possi l to dd som full or ng lt rs on t kground lig ts n t is s t kground will s ift d twi of full or ng w i m k s t kground ompl t ly ompr ss d in t or ng su sp of t r pr s nt tion

ur m t od impli s mor pow r to lig t n t for ground t n in lu s r n m t od, for inst n , f t lig t sour is n qu l n rgy lig t, nd t lt rs ppli d on t lig t sour nd l ns r r sp tiv ly full lu nd full

or ng lt r, t m r will s only 10 to 30 of t n rgy of t lig t sour ow v r id ls lt rs sp trum of t orr tion fl t for v ry) ould m k t m r s 50 of t sour n rgy us d not r w y for orr ting t s ift loosing l ss n rgy, using w it l n orr tion inst d of full or ng lt r on t l ns s

om v ry int r sting f tur s r positioning t is m t od s n lt rn tiv to t popul r lu s r n m t od s t r d r s pro ly noti d, w don't n d to v p rti ul r kground T st s n rio would to lig t n t kground wit its most ompl m nt ry olor T is m t od do sn't d m nd p rf tly uniform lig t on lu w ll Lig t ning it will noug Lik in t rom -k y pro ss, t l k surf s will diffi ult p rt to pro ss us l k is v ry s nsitiv to nois in olor n our post pro ssing orr tion w r mov t l k und r t r s old nd r pl t m y int rpol tion using t n ig ors of t r mov d r

T is m t od n lso work for outdoor s n s n p otogr p rs r usu lly using gold n r fl tors to simul t suns t, t y r in f t s ifting t for ground wit lig t tint d diff r ntly t t t kground orr tion on t l ns is don y t ompl m nt ry lt r to t r fl tor

2.3 The Cameras

stimulus is r li d wit t r r ys of lig t only, t v lu s , nd r in f t p r nt g of t prim ri s to mix to g t quiv l nt stimulus

T m r is l to djust its w it l n in fun tion of t tint of t lig t sour T following qu tions r l t t , , vid o v lu s) to t tristimulus v lu s , nd it will us ful for t olor orr tion pro ss)

$$\begin{bmatrix} \\ \\ \\ \end{bmatrix} \quad \begin{bmatrix} & 0 & 0 \\ 0 & & 0 \\ 0 & 0 & \end{bmatrix}^{-1} \begin{bmatrix} & & \\ & & \\ & & \end{bmatrix}^{-1} \begin{bmatrix} \\ \\ \\ \end{bmatrix} \qquad 7)$$

wit

$$\begin{bmatrix} \\ \\ \\ \end{bmatrix} \quad \frac{1}{\ _w} \begin{bmatrix} & & \\ & & \\ & & \end{bmatrix}^{-1} \begin{bmatrix} _w \\ _w \\ _w \end{bmatrix} \qquad 8)$$

w r , , , , , , , , , $_w$, $_w$ nd $_w$ r r sp tiv ly, t oordin t s of t r d, gr n nd lu prim ri s in NT nd of t w it of r f r n

T s ond possi ility to orr t t s ift don y t lu lt r on t for ground lig t, is to djust t w it l n on t n w olor o t in d y t sour t lt r oos to put t lu lt r on t lig ts us t w it t 3200K of t ul is oost d to 4000K lf lu lt r) nd 5000K full lu lt r) w i m k s t w it l n possi l

n t is s , s xp t d, t only sorption of lig t is don y t lu lt r T r sult is tt r t n t on w got in t form r m t od r t for ground s ift is prop rly orr t d, nd t kground is t n s ift d in or ng t s m w y T limit of t is m t od is t possi ility for t m r

to do t w it l n or inst n , m r is not l to orr t s ift don y or ng lt r on t 3200K lig t, ut would p rf tly l to orr t s ift don y n or ng lt r on lig ts

mixtur of t two m t ods mig t wort to us

3 Color Correction

propos t following m t od to p rform orr tion in ord r to m lior t n im g , or in ord r to r tri v olor s ift du to non- ompl m nt ry lt rs in t rst m t od T is olor orr tion m y lso int r st t os w o r on rn y vid o s qu n quir d wit poor w it l n d nd w nt to r tri v mor pt l r sult

will try to simul t t r l stimuli, s d on t d t w quir d T rst st p is to nd t r l w it of t im g w r n ly ing T is m y giv n m nu lly y indi ting w it of r f r n , or utom ti lly if on s s ot olor rs, w i is t s in our xp rim nts us d 75 olor r rt wit 100 w it r f r n , in ord r to r t mod l for our m r for som p rti ul r s ifts rst s ot t rt und r t 3200K lig ts nd tun d t w it l n to g t t st w it s possi l on t v tor s op T is rt is t n our r f r n for t visi l sp trum n furt r work w will pro ly d sign our own rt in luding mor olors w l of 300 li r t d olors) ft r s ooting t is rt on und r t r f r n lig t, nd s ond tim und r t s ift d lig t, w r l to r t ro ust mod l of t m r us d nd for p rti ul r s ift ur urr nt mod l is only using 6 olors for int rpol ting t ntir sp trum, ut t orr tion o t in d is lr dy quit int r sting

sing t r pr s nt tion of olor xtr t d from t olor r, w rst r tri v t orr t tint of t stimuli N xt w orr t t purity of t olor o t in d using our mod l om post pro ssing r ppli d in ord r to tr t t l ks diff r ntly

3.1 White Retrieval

r w d s ri ow to orr t lf or ng s ift it t inv rs m trix 7), w omput t position of t m n of t 100 w it in rom ti ity di gr m T following dis ussion d n s s t w it of r f r n

$$[\quad 0\ 3486 \quad 0\ 3517]$$

n int r sting w y of orr ting t s ift d olor rs is to nd t stimulus ompl m nt ry to t w it w found r , nd us t is n w v lu s t w it pp ring in qu tion 8)

r looking for t stimulus w i giv s t w it w n mix d wit t w it s ift d ov

o *o* *o* *o* *o* *o*

r indi s , nd orr spond to t w it , stimulus ompl m n- t ry nd t w it s ift d n oos r itr rily 1, us w r just int r st d y t r l tiv lumin n T n, t qu tions ov om

$$— \quad — _o \quad — _o \quad 1 \quad _o \quad _o \quad — \quad — _o \quad — _o$$

wit $1 -$ $-$ $_o$ $1 -$ $_o -$ $_o$ $_o$ $1 -$ $_o -$ $_o$

w nd t t r stimuli r on t s m lin ving t is following qu tion

$_o$ $_o$ w r $\frac{-}{-}$, nd $-$

Now t k t ompl m nt ry stimulus to $_o$,w i s t s m lumin n $_o$ $_o$ $_o$ nd $_o$ will in t s m lumin n pl n)

T n 2 $_o$, or $_o$ $_o$ $\frac{1}{2}$ g t $_o$ 0 2787 nd $_o$ 0 2872

Now, w onv rt t v lu s to stimuli using t inv rs m trix of qu tion 7) nd using $_o$, $_o$ nd $_o$ s t w it igur 3 omp r s t n w stimuli, t r f r n olor rs nd t s ift d olor rs v r pr s nt d

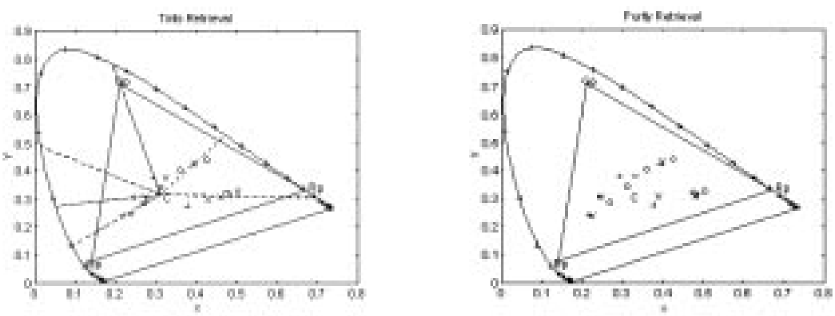

Fig. 3.) pr s nt tion of t r tri v l of t tints of n lf or ng s ift d olor rs rt) sult of t purity orr tion in t di gr m r pr - s nts t f r n olor rs oordin t s, t lf or ng s ift d olor rs nd t orr t d olor rs

t tints of t r f r n olor rs dott d lin s) igur 3 s ows t t t gr n nd m g nt r littl it diff r nt from w t t y s ould , ut t ot r tints r pr tty orr tly r tri v d

T is r sult is not y t w t w w nt v n if t tints r lmost orr t, t purity of t s olors r quit diff r nt of t r f r n olor rs purity T n xt st p is to r li lt r of purity

igur 4 r pr s nts t purity lt r, w r t ngl s xpr ss t tints nd t norm , t r tio $\frac{r\ (\ )}{(\ )}$) us d only six olors to g n r t t is fun tion y int rpol tion T is fun tion is r l t d to t r l s nsitivity urv s

of our m r T is r pr s nt tion is quit t s m s t u r pr s nt tion in t olor sp T r sult of olor orr tion is pr s nt d in igur 3

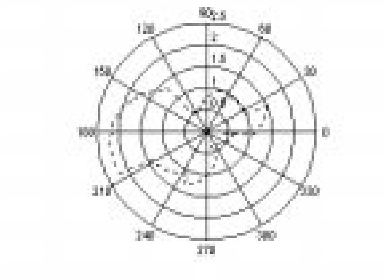


Fig. 4.) tor s op r pr s nt tion of t purity lt r,) im g to s gm nt

4 Segmentation Using the SVD Method

oos s mpl from t kground to pply st tisti l m t od to s g- m nt t s n T r for if n w o j t pp rs in t for ground it is not n ss ry to ng our s n kground- s d initi li tion l ssi d t s ift d olors using m t od of s gm nt tion lust ring m t od w s us d to group t s ift d olors into s nsi l s ts in t olor sp T w s ppli d to lust r nd r sult d in r t ri ing group d olor wit p r m t rs of 2-sigm llipsoid T llipsoid is proj t d onto t ro- m ti ity su sp

4.1 Applying the SVD Segmentation

T singul r v lu d omposition provid s two n ts in t is work 10 irst, w xploit t id t t t ov ri n of olor s mpl n f tor d into ^{t} r , t m trix r pr s nts n tur l sis for t x s long t prin ip l ompon nts ^{t} is t lin r tr nsform tion from t s mpl d sis to t n tur l sis of t prin ip l ompon nts ond, t v ri n long t prin ip l ompon nts r giv n y t singul r v lu s in L T v ri n is s l d y n r itr ry onst nt ^{2} n t is sso i tion is r l t d to t d sir d sigm v lu t t r t ri s t olor s mpl

4.2 Clustering

rly t sting s ow d kgrounds t t w r wid ly spr d ross t rom ti - ity su -sp r sult d in lust rs t t w r too l rg ppli d lust ring m t od to d l wit t is issu lust ring m t od su s t K-m ns l- gorit m 11 n ppli d to t s ift d olors us d modi d v rsion of t K-m ns lgorit m T ntir kground is rst s mpl d T singul r v lu d omposition is ppli d to d ompos t olor s mpl ov ri n m trix

into its prin ip l ompon nts ingul r v lu s provid d y t r pr s nt t v ri n for t prin ip l ompon nts v lu t t v ri n g inst t r s old f t m ximum singul r is ig r t n t s l t d t r s old, t d t is split long yp r-pl n t t is ort ogon l to t prin ip l xis wit t m ximum v ri n T pro ss is r -it r t d for r sulting lust r until t singul r v lu s for lust r r wit in t t r s old onstr ints found t r sults r not ppr i ly diff r nt from on olor sp to not r

4.3 Segmenting a Clustered Color Sample

onsid r xtr ting s mpl s t of m points from t rg t, w r t olor sp is d n d s d on t NT r iv r prim ry syst m d nition pix l s mpl d n r pr s nt d t oordin t in olor sp T s mpl d m n for s t in is d t rmin d s

$$[\quad g \quad]^t \quad \frac{1}{\quad}[\textstyle\sum_{=1} \quad \sum_{=1} g \ \sum_{=1} \quad]^t \qquad 9)$$

w r t ntri s of $[\quad g \quad]^t$ r pr s nts t m ns of ompon nt wit in t s t of int r st irst onsid r pplying t is t niqu to on s t of s mpl d d t , t n t r sult s own n xt nd d to multipl s ts w r s mpl s n p rtition d into multipl su - lust rs T v ri n n us d to st lis st llipsoid in sp t t ont ins t d sir d s t of pix ls for ny v ri n n omput d, it is n ss ry to rry out tr nsform tion to n w sis nt r d out t s mpl d m n T n w sis is to lin d up wit n stim t of t st prin ip l xis of t s mpl d d t T tr nsform tion xtr t d from t gu r nt s t stim t d prin ip l ompon nt x s r ort ogon l T r for t st tisti s r d - oupl d w n stim t d long t prin ip l ompon nt x s

point onsists of t r v lu s orr sponding to t r d, gr n, nd lu ompon nts of olor sp L t t s t of points form d into m trix , w r is , wit 3, nd onsid r tr nsl ting t xis y − su t t t s t of s mpl d points is tr nsform d to ro-m n s t long its prin ip l ompon nts y ^{t} −) w r t tr nsform tion is found from impl m nting t

L t t ov ri n m trix for ll t s mpl d d t points r pr - s nt d s t olumns of or s mpl d s t of d t , t ntri s for t ov ri n m trix r giv n s in 10)

$$\begin{bmatrix} & & \\ & & \\ & & \end{bmatrix} \qquad 10)$$

w r $\frac{1}{\ }\sum_{=1} \quad - \ )^2$, $\frac{1}{\ }\sum_{=1} g \ - g)^2$, $\frac{1}{\ }\sum_{=1} \quad - \ )^2$ nd $\frac{1}{\ }\sum \quad 1 \quad g\ ) - \ g$ $\frac{1}{\ }\sum \quad 1 \quad\ ) -$ $\frac{1}{\ }\sum \quad 1 \quad g\ ) - \ g)$

t is int r sting to not t t is t s m , w t r t is p rform d on t d t its lf or t ov ri n m trix T import n is t t t olumns of sp n t sp of nd r t d sir d ort ogon l sis v tors orr sponding to t prin ip l v lu s for t tr nsform d llipsoid T d t ont in d in n tr nsform d to t ro-m n s t −) T olumn v tors in m trix g t tr nsform d into t n w r ng sp y 9) w r is , wit 3, nd

$$ {}^{t} \quad - \;) \qquad (11) $$

T m trix ont ins t tr nsform d v tors $[\ \ \gamma\,\beta]^t$ T s mpl d d t is ssum d to norm lly distri ut d T tr nsform d d t ont in d in is lign d wit t prin ip l x s nd t v ri n of t d t n found from 12)

$$ {}^{2} \quad \frac{\sum_{=1}(\quad - \hat{\ }\ )^2}{-1} \qquad {}^{2}_{\gamma} \quad \frac{\sum_{=1}(\ {}_{\gamma} - \hat{\ }_{\gamma})^2}{-1} \qquad {}^{2} \quad \frac{\sum_{=1}(\quad - \hat{\ }\ )^2}{-1} \qquad (12) $$

t is sy to s ow t r sult of qu tion 12) n o t in d dir tly y pply- ing t to t ov ri n m trix inst d of t d t its lf s pr viously st t d, t tr nsform tion will id nti l, ow v r t singul r v lu s o - t in d from impl m nting t is m t od on t m trix r t v ri n s ^{2}, $^2_{\gamma}$, ^{2} T s v ri n s r pr s nt t ig nv lu s of t ov ri n m trix

4.4 Establishing Sets of Probable Points

of t t r v lu s of t v ri n d t rmin d y pplying t r p- r s nts t int rs tion of t on -sigm llipsoid wit it r t s mi-m jor or on of t s mi-minor x s n llipsoid w s s l t d s t ounding g om try us t lo tion of its ounding surf is w ll und rstood w n t d t is norm lly distri ut d sing t s on -sigm v lu s s r t risti p r m t rs d s ri ing t ound ry of s t of int r st m ns t t 63 of t s mpl d d t f lls wit in t s t ling t sigm v lu s y two or t r r sp tiv ly r sults in 86 nd 95 of t s mpl d d t f lling wit in t s t T r is tr d -off wit t s l tion of s l v lu for t sigm v lu n would lik to y- pot si t t ny r itr ry pix l m pp d into t st lis d ound ry from t tr nsform tion tu lly longs to t s t or ig r-s l d v lu s of sigm t r is ig r lik li ood t t pix l l ssi d in t s t do s not long T r r four possi l out om s to t ypot sis t st

1) pix l id nti d s longing to t s t of int r st longs to t s t 2) pix l id nti d s longing to t s t of int r st do s not long to t s t 3) pix l id nti d s not longing to t s t of int r st do s long to t s t 4) pix l id nti d s not longing to t s t of int r st do s not long to t s t

T stim t d v ri n s s ould s l d to m ximi t pro ility of onditions on nd four, nd minimi t pro iliti s of onditions two nd t r L t t p r m t r k t s l d v lu for t

T llipsoid in sp ounding t s t of points of int r st is

$$\frac{{}^2}{{}^2} \quad \frac{\gamma^2}{{}^2_{\gamma}} \quad \frac{\beta^2}{{}^2} \quad {}^2 \qquad 13)$$

w r k is t s l d v lu T p r m t r k is s l t d to optimi t out om of t ypot s s t sts s m ntion d ov point n t st d using qu tion 13) T ounding llipsoid n tr nsform d k into sp y t inv rs tr nsform tion s own in 14)

$$[\ \ g\ \ ]^t \qquad [\ \ \gamma\,\beta]^t\ \ T \qquad 14)$$

4.5 Procedure Summary

olor s gm nt tion using t m t od d s ri d r n omplis d s follows

1 t in s mpl from t t rg ts of int r st
2 ind t m ns for t rg t using 9), t n tr nsform s mpl s from t rg t su t t t y r ro m n s mpl s
3 s t singul r v lu d omposition to nd t tr nsform tion m trix for t rg t d t s t
4 p d t s t into r ng sp w r t d t is lign d wit t prin ipl x s using 11)
5 s 12) to nd t v ri n in t tr nsform d sp or us t ig nv lu s of t ov ri n m trix
6 f t v ri n is ov s l t d t r s old, p rtitioning t d t into su lust rs s r quir d
7 st lis t ound ri s of t s mpl s t s n int rs tion of lust rs found for t rg t using 13) ppli d to lust r
8 s t n visu li d y tr nsforming t s t ound ri s k into t sp y t inv rs tr nsform tion of 11)
9 T st pix l in t ntir im g , or sm ll r r of int r st wit in t im g to d t t t t rg t

5 Experiment and Conclusion

n ord r to g t t st r sult w s mpl d t r r gions igur 5) of t rst pi tur igur 4) of vid o s qu n , nd ppli d t r tim s our s d s gm nt tion m t od T t r s mpl s w r t k n in t s m r s in t two s qu n s non s ift d nd s ift d) T rst s mpl is low r solution s mpl orr sponding to n ori ont l sli of t kground, for ot s qu n s w r j t d ny v lu s gr t r t n 4 st nd rd d vi tions T is rst r sult is lr dy int r sting w n w onsid r ow olorful w s t origin l kground T s ond s mpl is p rt of t f nd w k pt t v lu s ompris in 3 8

st nd rd d vi tions, t l st s mpl is t k n in t ir w r t tol r n w s 1 6 st nd rd d vi tions sults of s gm nt tion igur s 5 nd 5)

v pr s nt d n w m t od to lust r t kground to improv s gm nt tion pro ss

T prin ipl is r l tiv ly simpl nd would sk l ss r in s ooting t n t tr dition l lu s r n m t od or t oug , multipl m r s ooting would possi l T is on pt is lmost impossi l wit lu s r n m t od ur r sult is not p rf t ut s to omp r d to tr dition l m t ods su

Fig. 5.) mpl s for im g s,) rigin l im g s gm nt tion) ift d im g s gm nt tion

s rom -k ys it su ompl x s n t st rom -k y would v giv n wors r sult t n m t od ppli d to t non s ift d im g T limit tion of our m t od is for s gm nting d rk olors, t l k of lumin n is n import nt sour of nois in vid o To r solv t is pro l m w will mix t is m t od to not r typ of s gm nt tion motion tr king, dg d t tion or d pt stim tion) n t is pr s nt tion w w nt d to g t t st r sults for t worst onditions Two m in ontri uting f tors to d gr d d onditions r ompl x kground s n nd n off-t -s lf vid o m r T n to improv t r sults on would just v to g t mor pr is m r su s ny tripl - s d or ro d st qu lity m r T kground will r lly simpl r in n tur l or studio nvironm nt , ut it s not to p rf tly uniform lik in t lu s r n m t od

lso pr s nt d olor orr tion m t od s d on t stimuli p r ption r tri v l T is orr tor ould v mor g n r l us in postprodu tion ppli - tions t n t on pr s nt d r

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Designing Emergence in Animated Artificial Life Worlds

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Abstract. A methodology is described for designing real-time animated artificial life worlds consisting of populations of physically-based articulated creatures which evolve locomotion anatomy and motion over time. In this scheme, increasing levels of emergent behavior are enabled by designing more autonomy into the simulation on progressively deeper levels. A set of simulations are discussed to illustrate how this methodology was developed, with the most recent simulation demonstrating the effects of mate choice on the evolution of anatomies and motions in swimming creatures.

1 Introduction

The art of animation as invented by the Disney animators has been called "The Illusion of Life." It seems that Computer Animation as a craft has never really caught up to the expressivity, humor, and lifelike motion possible with classic cel-based character animation. The animators at Pixar have been successful at adapting computer technology to the fine art of classic character animation technique. But as feature film animators refine this marriage of new and old technologies, a new form of animated character emerges, not in the film industry but from within various artificial life labs. Add to Disney's "Illusion of Life," the "Simulation of Life," and witness a new technology–one which is compatible with the goals of Virtual Reality–a future cyberspace in which characters are not just animated: they are autonomous, reactive agents as well.

This paper describes an approach to artificial life (alife) [9], stemming from animated art and a design process for creating it. It is an exploration of autonomously generated motion and form. The original impetus is not biological science, although biology has become an important aspect of the work. The angle on alife discussed in the paper may provide ideas and techniques that are useful in creation of populated virtual worlds for entertainment, education, and research.

I will discuss a family of simulations which were built upon each other, in which populations of artificial creatures evolve anatomy and motion over time. In these simulations, emergent behavior is enabled by progressively designing levels of autonomy into the model. The simulations are used to illustrate how this methodology

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was built, with the most recent simulation demonstrating the effects of mate selection on the evolution of anatomies and motions in swimming creatures.

Future enhancements will include wiring up an evolvable nervous system connected to various sensors and actuators, within which neural net-like structures might emerge, potentially enabling the creatures to evolve higher-level stimulus-response mechanisms and "states of mind," which emerge through direct contact with the environment.

Design Considerations. A main goal of alife projects is to construct models in which self-organization and adaptive behaviors can arise spontaneously, not by design, but through emergence. A duality is observed in the creation of real-time alife worlds: while the goal of an alife simulation is emergence, it is ultimately a designed artifact. Creating alife worlds, in this methodology, is a matter of *designing emergence*.

One must choose a level of abstraction, below which a number of assumptions are made about the ontology supporting the model. Above this level of modeling, emergent phenomena arise as a product of the design of the subsystem when the model is run. For instance, many alife simulations model populations of organisms whose spatial positions are represented by locations in a cellular grid, and whose physical means of locomotion (jumping from cell to cell) are not clearly specified. The emergent properties in question may not require a deeper level of simulation than this. However, a simulation in which an articulated body plan is integral to locomotion (as well as reproduction) requires a lower level of abstraction, and a deeper physical model becomes necessary. More design may be required to build the simulation foundations, however, it may allow for more complex emergent phenomena.

Towards the quest for more autonomy, the most recent simulation in the set which I will discuss consists of a population of many hundreds of swimming creatures which animate in real-time. The creatures come in a large variety of anatomies and motion styles. They are able to mate with each other, and choose who has the "sexiest" motions, enabling evolution of swimming locomotion and anatomy which is attractive (beauty of course being in the eye of the beholder). The best swimmers reproduce their genes (because they can swim to a mate), and the most "attractive" swimmers get chosen as mates. In this simulation, not only are the aesthetics of motion and form subject to the chaotic nature of genetic evolution, but the creatures themselves partake in the choice of what forms and motions emerge.

The methodology discussed in this paper includes the following key components:

- a morphological scheme with an embryology
- a motor control scheme
- a physics
- a nervous system
- genetic evolution
- computer graphics rendering

Each of these components are described throughout the sections below. They are not explained in great technical depth, but rather discussed as a general methodology, with some commentary.

1.1 Related Work

Early examples of using alife principles in computer animation include *Boids* [12], in which complex life-like behaviors emerge from many interacting agents. Badler [2] describes physically-based modeling techniques and virtual motor control systems inspired by real animals used to automate many of the subtle, hard-to-design nuances of animal motion. In task-level animation [22] and the space-time constraints paradigm [21] these techniques allow an animator to direct a character on a higher level.

The genetic algorithm [7, 6] has been used for the evolution of goal-directed motion in physically-based animated figures, including a technique for evolving stimulus-response mechanisms for locomotion [10]. Sims [14, 15] has developed impressive techniques for the evolution of morphology and locomotion using the genetic programming paradigm [8]. Also, a holistic model of fish locomotion with perception, learning, and group behaviors, which generates beautifully realistic animations, was developed by Terzopoulos, Tu, and Grzeszczuk [16].

1.2 Walkers

The first project in the series began an attempt to build a 3D stick figure which could stand up by way of internal forces bending various joints. The original goal was to model a human-like form, but this was too large a task at the time. To simplify the problem, the bipedal figure was reduced to the simplest anatomy possible which can represent bipedal locomotion: two jointed sticks, called "Walker," shown in Figure 1a.

Performance artists Laurie Anderson once described walking as a continual process of catching oneself while almost falling, by placing one foot out in the direction of the fall, stopping the fall, and then almost-falling again [1]. This notion inspired the idea to construct a 3D bipedal figure which has mass and responds to gravity and which is always on the verge of falling over and so must continually move its legs in order to keep from falling, to stay upright, and to walk.

Walker's "head" experiences a pull in the direction of its goal (an inaccurate model of the desire to be somewhere else, yet sufficient for this exploration). Walker can perceive how much its body is tilting. The amount of tilt is used to modulate the motions in its legs. As it's head is pulled towards its goal, its legs move in such a way as to keep it upright and afford locomotion. Internal forces cause the legs to rotate about the *head joint*, back and forth, in periodic fashion, using sine functions. Parameters in the sine functions for each leg, such as amplitudes, frequencies, and phases, are genetically determined, varying among a population of Walkers, and are allowed to evolve over time within the population. Responses to body tilt are also genetically determined.

At the start, the motions of most of the Walkers are awkward and useless, with much aimless kicking, and so most of the Walkers immediately fall as soon as they are animated, although some are slightly better at staying upright for longer. By using a simplified genetic algorithm which repeatedly reproduces the best Walkers in the population, with chance mutations, and killing off the rest, the population improves locomotion skill over time.

To demonstrate Walker's ability to react to a constantly changing situation, a virtual "leash" was attached to the head, which a user could gently pull around. Also, sce-

narios were constructed in which multiple Walkers had attractions and repulsions to each other, generating novel pursuit and evasion behaviors.

Walker is the first in a series of alife creatures in this system consisting of linked-body parts which are connected at their ends and which can rotate about each other. Figure 1b shows a creature from a later simulation of 2D creatures consisting of five interconnected segments, with four effective joints. As in the case of Walker, rota tions about the joints are controlled by sine functions with evolvable parameters. Fitness in this scheme is based on distance traveled. Although creatures in this population are 2D, locomotion is possible, with evolved populations consisting of creatures ambulating either to the left or to the right.

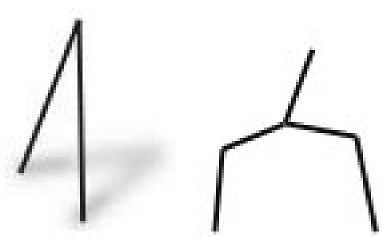

Fig 1. (a) Walker, (b) 2D walking figure.

2 A Morphology Scheme

It is one thing to link together a set of sticks in a predetermined topology and then allow the motions of the joints to evolve for the sake of locomotion. It is another thing entirely to allow morphology itself to evolve.

In the next incarnation of this alife methodology, a morphological scheme was designed which allowed the number of sticks, lengths, branching angles, and stick topology to vary. All of these factors are genetically determined. An important principle in this newer morphological scheme is that in this case, there are no implied heads, legs, arms, or torsos, as shown in Figure 3. Creatures are open-ended structures to which Darwinian evolution may impart differentiation and afford implicit function to the various parts.

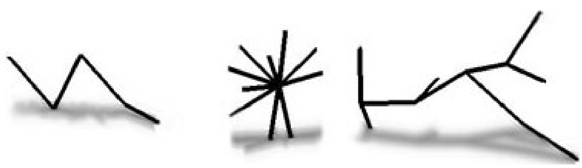

Fig. 3. 3D creatures with variable morphology.

An extension of this scheme includes bodies with variable thickness among parts. Figure 4 shows a representative 3D creature from this set. These creatures are the most complex of all the morphological schemes, and can exhibit locomotion schemes and anatomies which exploit the effects of uneven distributions of mass among the body (consider for instance the way a giraffe uses the inertia of its neck when it runs). The figure in this illustration uses a tripod technique to stabilize itself. Creatures in this scheme tend to evolve 3 or 4-legged locomotion. Bipedal locomotion does not evolve: this is probably due to the fact that they have no sensors for balance, and thus no way of adjusting to tilt (as Walker did). A future enhancement will be to add 3D "vestibular" sensors, to enable bipedal locomotion.

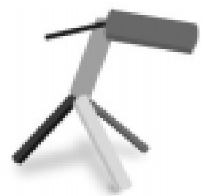

Fig. 4. A 3D creature with variable thickness in parts.

2.1 Embryology

Each creature possesses a set of genes organized in a template (the genotype). Genotypes are represented as fixed-length strings of real numbers. Each gene is mapped to a real or integer value which controls some specific aspect of the construction of the body, the motion of body parts, or reactivity to environmental stimuli. Genotypes get expressed into phenotypes through this embryological scheme. The typical genotype for a creature includes genes for controlling the following set of phenotypic features:

number of parts
the topology (branching order) of parts
the angles at which parts branch off other parts
colors of parts
thicknesses of parts
lengths of parts
frequencies of sine wave motions for all parts
amplitudes of sine wave motions in each part
phases among sine wave motions in each part
amplitude modulators of each sine wave (reactivity)
phase modulators of each sine wave (reactivity)

The design of a genotype-phenotype mapping has been one of the most interesting components of the design process in building alife worlds in this scheme. It is not always trivial to reduce a variable body plan to an elegant, simple (and evolvable) representation. Dawkins [5] promotes the concept of a "constrained embryology,"

whereby global aspects of a form (such as bilateral symmetry or segmentation) can be represented with a small set of control parameters. A representation with a small set of genes which are able to express, through their interactions during embryology, a very large phenotypic space, is desirable, and makes for a more "evolvable" population.

2.2 Motor Control

The motor control scheme in this system is admittedly simplistic. Real animals do not move like clockwork, and do not move body parts in periodic fashion all their lives. However, as mentioned earlier, one must choose a level of abstraction. For the simulations designed thus far, this simplistic model of animal locomotion has been sufficient. Also, the addition of modulators to the periodic motions makes the motion less repetitive, and enables reactivity to the environment. A more reactive motor control scheme would be required if any behavior other than periodic locomotion is expected to evolve.

3 Physics

This alife system evolved from a simple animation technique whereby motion was made progressively more complex. The notion of a physics also became incorporated in progressive steps. In the figures modeled in this scheme, deeper levels of physical simulation were added as needed, as more complex body plans were designed.

In the present scheme, time is updated in discrete steps of unit 1 with each time step corresponding to one update of physical forces and one animation frame. A creature is modeled as a rigid body, yet which can bend its parts as in an articulated body. Torque between parts is not directly modeled in this scheme. The effects of moments of inertia and changing center of mass are modeled. A creature's body has position, orientation, linear velocity, and angular velocity. Position and orientation are updated at each time step by the body's linear and angular velocities. These are in turn affected by a number of different forces such as gravity, collisions of body part endpoints with the ground (for terrestrial creatures), forces from parts stroking perpendicular to their axes in a viscous fluid (for sea creatures), and in some cases, contact with user stimulus (a mouse cursor which pokes into the virtual space).

4 Nervous System

It is possible that brains are simply local inflammations of early evolutionary nervous systems, resulting from the need in early animals to have *state* and generate internal models in order to negotiate a complex environment. This is an alife-friendly interpretation of brains. The design methodology employed here is to wire up the creatures with connectivity and reactivity to the environment, and then to eventually plug in evolvable neural nets which complexify as a property of the wiring to the environ-

ment. Braitenberg's Vehicles [3] supply some inspiration for this bottom-up design approach.

The design philosophy used here does not consist of building a brain structure prior to understanding the nature of the organism's connectivity to the physical environment. If adaptive behavior and intelligence are emergent properties of life, then it is more sensible to design bodies first, and to later wire up a proto-nervous system in which brains (might) emerge. The "Physical Grounding Hypothesis" [4], states that to build a system that is intelligent it is necessary to have its representations grounded in the physical world.

In this system, there are not yet any brains to speak of. It includes a simple mental model which is (at this point) purely reactive: sensors in a creature detect aspects of the its relation to the environment, which can directly transition its state to another state, or which directly control actuators (real-time changes in the motions of body parts). For instance, while in "looking for mate state", a creature will react to certain visual stimuli, which can cause it to enter into a new state, such as "pursuing a mate". A future enhancement includes building an evolvable recurrent neural net which mediates the sensor-actuator pathways, and can grow internal structure and representation in the context of the creature's direct coupling with the dynamic environment.

5 Evolution

Models of Creationism are made implicit every time a craftsperson, animator, artist, or engineer designs a body of work and establishes a methodology for its creation. Darwinian models are different than Creationist models (though not absent of a creator). In Darwinian models, important innovation is relegated to the artifact. Invention happens after initial Design. Surprises often result. Genetic algorithms are Darwin Machines [11], designed to take advantage of lucky mutations. They are serendipity engines.

The earlier alife simulations discussed use a variation of the standard genetic algorithm: hundreds of creatures are initialized with random genes, then each is animated for a period of time to establish its fitness ranking (in most cases, determined by how far it has traveled from the position at which it started). After this initial fitness ranking, a cycle begins. For each step in the cycle, two statistically fit individuals are chosen from the population, mated, and used to create one offspring which inherits genes of both parents through crossover. The offspring undergoes embryology and then replaces the least fit individual in the population. The offspring is then animated to determine its fitness. The process continues in this way for a specified number of cycles. This technique guarantees that overall fitness never decreases in the population. The most fit creatures are never lost, and the least fit creatures are always culled [17]. Figure 5 shows 4 snapshots of a locomotion cycle showing a 3-legged anatomy and locomotion strategy, which evolved from one of these simulations.

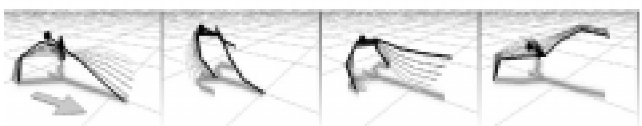

Fig. 5. An evolved 3-legged locomotion strategy.

6 Sexual Swimmers

In the latest series of simulations, dimensionality was brought down from three to two, but the model was deepened by allowing reproduction to be spontaneous. To ground the simulation more in a physical representation, the concept of a "generation" was blurred. Instead of updating the entire population in discrete stages (a schedule determined by the "creator"), this system allowed reproduction to occur asynchronously and locally among creatures able to reach proximity to each other in a spatial domain. The notion of an explicit fitness function is thus removed [18].

Locomotion behavior evolves globally by way of local matings between creatures with higher (implicit) fitness than others in the local area. Figures 6a and b illustrate two swimming styles which emerged from this simulation.

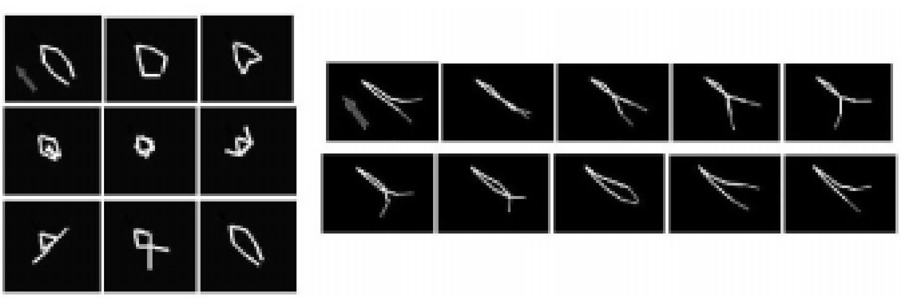

Fig. 6. Sequences of images of swimming strategies: (a) paddling-style, and (b) undulating-style, which emerged through evolution.

Turn That Body. In order to pursue a potential mate which is swimming around (possibly pursuing its own potential mate), a swimming creature has to be able to continually orient itself in the direction it wants to go. A reactive system was designed which allowed the creatures to detect how much it would need to turn its body while swimming (analogous the the "tilt" sensor in Walker, only now covering 180 degrees in a plane). Essentially, the creature senses the angle between the direction of its goal and its own orientation as the stimulus to which it reacts, as shown in Figure 7.

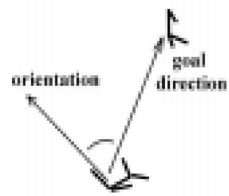

Fig 7. Turning stimulus

As opposed to Walker, which experiences a "magic pull" in the direction of its goal, these creatures must create their own means of propulsion, using friction with the surrounding fluid.

Since the number of possible morphologies and motion strategies in these creatures is vast, it would be inappropriate to top-down-design a turning mechanism. Since turning in a plane for a 2D articulated body can be accomplished by modulating the phases and amplitudes of certain part motions, it was decided that evolution should be the designer, since evolution is already the designer of morphology and periodic motion. Thus, modulator genes (shown in the list above) were implemented which can affect the amplitudes and phases in each part's motions in response to the stimulus.

A commercial product was derived from this simulation and called "Darwin Pond" [13]. It enables users to observe hundreds of creatures, comprised of 2D line segments, representing a large phenotypic space of anatomies and motions. They can be observed in the Pond with the aid of a virtual microscope, allowing panning across, zooming up close to groups of creatures, or zooming out to see the whole affair. One can create new creatures, kill them, move them around the Pond by dragging them, inquire their mental states, feed them, remove food, and tweak individual genes while seeing the animated results of genetic engineering in real-time. Figure 8 shows a screen shot of the basic Darwin Pond interface.

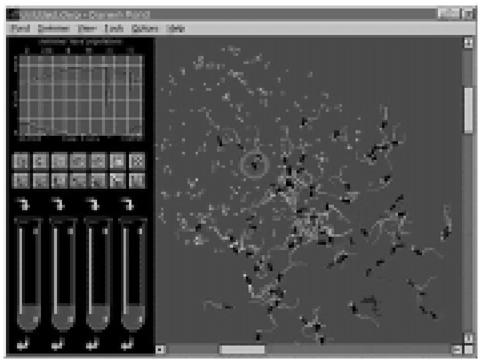

Fig. 8. *Darwin Pond* interface.

Physics and Genetics Are Linked. It is important to point out that in this simulation, genetic evolution is totally reliant on the physical model which animates the creatures. Not only does it take two to tango, but they have to be able to swim to each other as well. In this simulation, genotypes are housed in physically-based phenotypes, which, over evolutionary time, become more efficient at transporting their genotypes to other phenotypes, thereby enabling them to mate and reproduce their genes. This is the selfish gene at work. The emergence of locomotive skill becomes meaningful therefore in the context of the environment: it becomes physically grounded, and the fitness landscape becomes dynamic.

A variation on this simulation, called "Gene Pool" [20], was developed, and included a larger genotype-phenotype scheme, variable thickness in body parts, a deeper physics, and a conserved energy model. Figure 9 illustrates a collection of these 2D swimming creatures (before evolution has had any effect of body plan). They are called "swimbots".

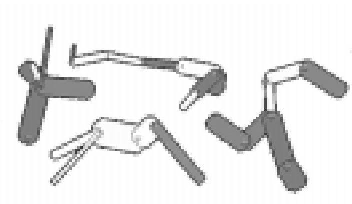

Fig. 9. Swimbot anatomies

What's Sex Got To Do With It? *Gene Pool* introduces mate choice in the process of reproduction. In this scheme, not only is the evolution of form and motion more physically grounded, and subject to the local conditions of the simulated world, but the aesthetic criteria which determine the "sexiest" motions also become a factor for reproduction.

What does "sexy" mean? Sexual selection in evolution is responsible for phenomena such as the magnificent peacock tail, and the elaborate colorful dances of many fish species, which sport curious body parts, adapted for mate attraction. Attraction-based features in many species may be so exaggerated and seemingly awkward that one would assume they decrease the overall fitness of the species, in which locomotion efficiency, foraging, and security are important. I arrived at an hypothesis: could mate preferences for arbitrary phenotypic features inhibit the evolution of energy-efficiency in a population of locomotive creatures? For instance, if the creatures in the population were attracted to slow-moving bodies, and only mated with the most stationary creatures in the population, would locomotion skill emerge? If so, what kind? What if they were all attracted to short, compact bodies? Would the body plan become reduced to a limbless form, incapable of articulated locomotion? If they were attracted to wild, erratic motion, would the resulting swimbots be burning off so much energy that they usually die before reproducing?

As an experiment, a simulation was built, including a variety of mate preference criteria determining which swimbots would be chosen [19]. In choosing a potential mate, a swimbot would take snapshots of each swimbot within its local view horizon, and then compare these snapshots and rank them by attractiveness. Criteria settings included: attraction to long bodies; attraction to lots of motion; attraction to bodies which are "splayed out," and attraction to massive bodies. The inverses of each of these phenotypic characteristics were also tested. As expected, in simulations in which length was considered attractive, populations with elongated bodies with few branching parts emerged. In these populations, locomotion was accomplished by a tiny paddle-like fin in the back of the body, or by gently undulating movements. Figure 10 illustrates a cluster of swimbots resulting from this simulation.

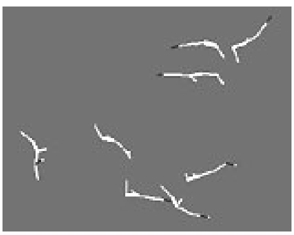

Fig. 10. Swimbots which evolved through mate preferences for *long* bodies.

Attraction to "splayed-out" bodies (in which the sum of the distances between the midpoints of each part is larger than average), resulted in creatures which spent a large part of their periodic swimming cycles in an "open" attitude, as shown in Figure 11. In this illustration, the creature is seen swimming to the lower right. Approximately one swim cycle is shown. Notice that the stroke recovery (the beginning and end of the sequence) demonstrates an exaggerated "opening up" of the body. It is likely that this behavior emerged because snapshots can be taken at any time by creatures looking for a mate, and so the more open a potential mate's body is, and the longer amount of time it is open, the more *attractive* on average it will be.

These experiments show how mate preference can affect the evolution of a body plan as well as locomotion style. The effects on energy-efficiency were non-trivial: locomotion strategies emerged which took advantage of attraction criteria yet were

still efficient in terms of locomotion. As usual with many alife simulations, the phenotype space has unexpected regions which are readily exploited as the population adapts.

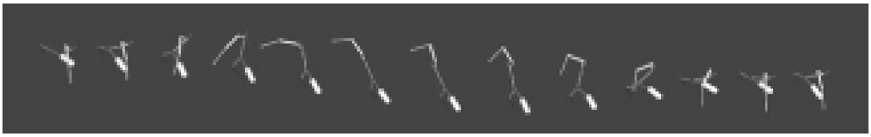

Fig. 11. Swimbots which evolved through mate preferences for *splayed* bodies.

6.1 Realtime Evolution

The alife worlds described here incorporate physical, genetic, and motor-control models which are spare and scaled down as much as possible to allow for computational speed and real-time animation, while still allowing enough emergent phenomena to make the experience interesting and informative. The effects of Darwinian evolution can be witnessed in less than a half-an hour (on an average Pentium computer). For educational and entertaining experiences, it is important that there be enough interaction, immersion, and discovery to keep a participant involved while the primordial soup brews. The average short-attention-span hardcore gamer may not appreciate the meditative pace at which an evolutionary alife system runs. But alife enthusiasts and artistically or scientifically oriented observers may find it just fine. For watching evolutionary phenomena, it sure beats waiting around a couple million years to watch interesting changes.

7 Computer Graphics Rendering

For the 3D stick figures, thick, dark 3D lines are drawn to represent the sticks. The interesting (and important) part comes in drawing a shadow, since this is largely the graphical element which gives the viewer a sense of the 3D geometry. The shadow is simply a "flattened-out" replica of all the lines (without the vertical component and translated to the ground plane) drawn with a thicker linewidth, and in a shade slightly darker than the ground color. Since no Z-buffering is used, the shadow is drawn first, followed by the sticks.

For the creatures with variable thickness in parts, a number of techniques have been used, many of them are graphics hacks meant to reduce polygon-count or to avoid expensive Z-buffering and lighting algorithms. Since these are specifically alife-oriented worlds, without any objects besides abstract articulated bodies, specific graphics techniques are used. At the point in which these creatures are imbedded in a more comprehensive virtual world, a more generalized renderer would be useful.

Rendering Behavior, Then Pixels. Part of the methodology is to take advantage of something that the eye-brain system is very good at: detecting movement generated by a living thing. It is important not to spend too much computational time on

heavyweight texturemaps, lighting models, and cute cosmetics, when more computation can be spent on deep physics and animation speed (to show off the effects of subtle movements that have evolved). It is a purist philosophy: simply show what is there. No pasting 2D images of eyes and ears on the creatures. Instead, as the simulation itself deepens (for instance, when light sensors or vibration sensors are allowed to evolve on arbitrary parts of bodies, as evolution dictates) graphical elements visualizing these phenotypic features will be rendered. They may be recognizably eye and ear-like, or they may not.

8 Commentary: Why Are There No Humanoids Here?

The goal of Artificial Intelligence research is something magnificent, and something very human indeed. It appears as if the skills enabling one to play chess and use grammar are a very recent evolutionary trend, whereas climbing a tree is a much older skill, truly more complex, and in fact possibly an activity whose basic cognitive mechanisms are the primordial stuff of higher reasoning.

These simulations do not aim to model humans. But if that were the goal, it may be best to design a vestibular system and an environment in which vertical, bipedal locomotion *might* be advantageous. Best to design an evolvable neural system (and to allocate lots of computer memory!) and a highly complex, dynamic environment, whereby something brain-like *might* billow like a mushroom cloud as an internal echo of the external complexity. Best to design a simulation in which objects existing in the world *might* be exploited as tools and symbols, extended phenotypes, cultural memes. What might evolve then could be something more human-like than the wiggling worms shown in the illustrations of this paper. But in the meanwhile, there is no rush on my part to get to human levels with these simulations. And at any rate, imaginary animals can be very thought-provoking.

9 Conclusion

In this paper, I have described many of the techniques, concepts, and concerns involved in a methodology for creating animated artificial life worlds. This approach does not begin with a biological research agenda but rather an eye towards the creation of forms and motions which are lifelike and autonomous–a branch of character animation. The alife agenda of studying emergent behavior by way of the crafting of simulations has become incorporated into this animation methodology, and with it, some key themes from evolutionary biology, such as sexual selection. It is hoped that these concepts and techniques will be useful for further advances in animated artificial life, for education, entertainment, and research.

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ALife Meets Web: Lessons Learned

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Abstract Artificial life might come to play important roles for the World Wide Web, both as a source of new algorithmic paradigms and as a source of inspiration for its future development. New Web searching and managing techniques, based on artificial life principles, have been elicited by the striking similarities between the Web and natural environments. New Web interface designs, based on artificial life techniques, have resulted in increased aesthetic appeal, smart animations, and clever interactive rules. In this paper we exemplify these observations by surveying a number of meeting points between artificial life and the Web. We touch on a few implementation issues and attempt to draw some lessons to be learned from these early experiences.

1 Introduction

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2 Applications to Web Search and Management

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x ut tion . tion v n n r o t ut m r ult in n r int . n-
r i u up n umul t int rn ll t rou out n nt li ; it int rn l
l v l utom ti ll t rmin r pro u tion n t v nt in w i n r
i on rv . nt t t p r orm t t tt r t n v r r pro u mor
n oloniz t popul tion. n ir t int r tion mon nt o ur wit out
t n o xp n iv ommuni tion vi omp tition or t r nit n-
vironm nt l r our . Mut tion n ro ov r or t n n r or
t volution o n mi ll pt nt . i p r i m n or n it -
p n nt l tion t xp t popul tion iz i t rmin t rr in
p it o t nvironm nt. o i tin i n r o t wit xp n iv -
tion intrin i ll n or l n n twor lo limitin in i nt u
o n wi t .

Collective Behavior pt tion m n or nt to on ntr t in i n-
r r o t w r m n o um nt r r l v nt. nt urviv l
will n ur x n in n qu t flow o in orm tion or n r .
itu tion i illu tr t t n p ot in i ur 1 illu tr tin t pi l oll -
tiv vior o n o pi r in r pon to qu r n limit to w ll n
un o t . t r w il lu nt v oun w t t u r w nt ;

t pro p r n multipl in t i r l v nt ni w il ot r nt ontinu to xplor t worl in r o lt rn tiv .

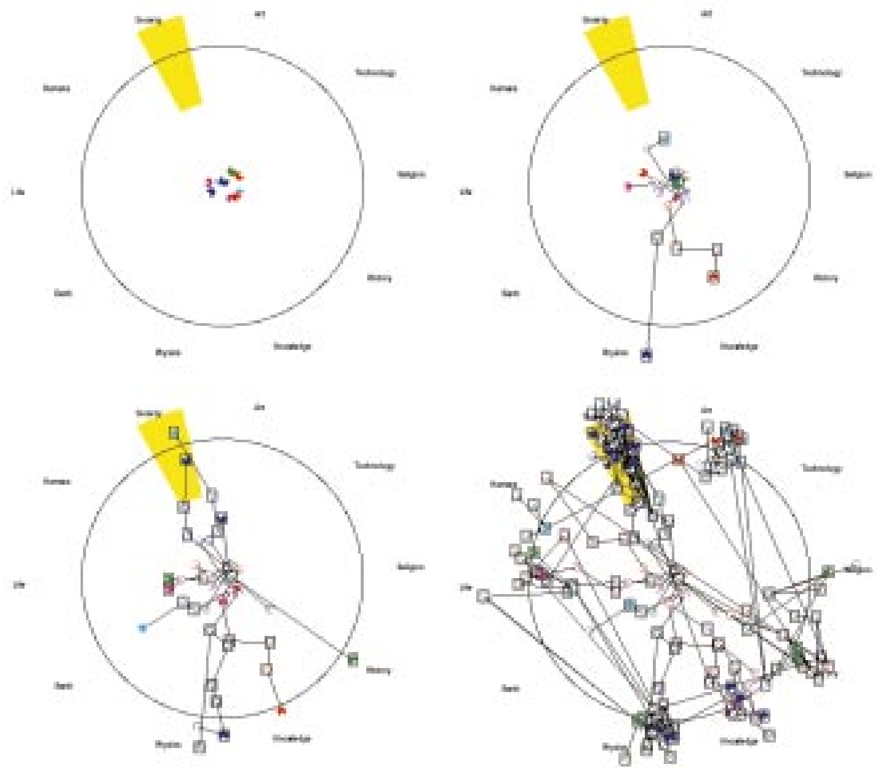

Figure1. n p ot o n o pi r r in t p or o um nt r l v nt to t qu r L w ov rnin r l tion mon ov r i n t t . o um nt ontolo i r pr nt wit mor p i topi rt r rom t nt r o t ir l n tu l rti l out i o t ir l . r l v nt o u- m nt r r pr nt t llow r un nown t to t nt . o u- m nt i m r wit r t n l i it i tim t r l v nt t r t nt vi itin it. olor o n nt r pr nt it lin o t t ll nt r- in olor n rom t m n tor. (t i ◯1997 n lop i rit nni n . 2 ; t vi u l r pr nt tion i t ut or .)

Search Efficiency On o t ntr l r ult o t n o pi r proj t i to v own t t it i u ul or in orm tion r l orit m to vi w t n tur l nvironm nt n r t riz it in u t rm . t r t n- vironm nt l t rom l rnin nt p r p tiv ? t ti ti l tur u

wor r qu n i r o our ru i l im n ion . t n r u t t t lin topolo tru tur impo in orm tion provi r upon t or- niz tion o o um nt i not r import nt r our . v n in un tru tur in orm tion nvironm nt ut or t n to lu t r o um nt out r l t top- i l ttin t m point to ot r. i r t l n p t t nt n xplor m in u o orr l tion o r l v n ro lin .

r limin r r ult on t or ti l n l i imul tion n tu l x- p rim nt on - orpor r v r n our in 14 . t n own t t lin topolo n in t t n xploit i tri ut nt outp r ormin x u tiv r n or r o m nitu . Mor ov r t n- r tw n volution l rnin n r l v n in u n ition l our- ol oo t in p r orm n 15 .

3 Applications to Web Interface Design

nt r i n ( ) i r ti ll n in in it p t n un tion- lit . t it i un l r in w t ir tion it i movin . r r t l t t r qu lit tor in ( ) l v r int r tiv rul ; ( ) m rt nim tion; n ( ) t ti pp l.[1] ntil r ntl int r tivit n m rt nim tion n - m or i rti i l int lli n t niqu r li onl on nim tor or pro r mm r iliti ; n t t ti pp l o r li uniqu l on r p i i n r iliti . ow v r in u r w nt to t out o t i un x it- in l n p t r i m n or mor pp lin or rti ti t ti mu m rt r — i not li -li — nim tion n mor l v r — i not um n-li — int r tion . Li t niqu pp r mon t rli t n mo t pl u i l n- i t to r om o t n . n in t r m in r o t i tion w ow om x mpl in w i Li lp u to ul ll t n provi in or n w w to int r t ( ) m in nim tion ri r n mor n tur l ( ) n xt n in t um n p iliti to uil t ti rti t ( ).

3.1 Web Interactive Cellular Automata

t n or nt r tiv llul r utom t . t i m o Li 13 (or n ot r) llul r utom ton 20 t t i ontroll r flowin t xt on n ML p . r flowin t xt i om tiv t xt t t w n li n mi ll n t t t o t llul r utom t . t w initi ll r t to upport - i n n provi pl in n in n unpr i t l ni- m tion or p lo o . t w t n xt n to upport n mi omput r rt n ot r in o ppli tion . om x mpl o n n on t om p 3 . nim tion m to lmo t r quir m nt in t ur- r nt ion o p ; om t in mu t lw mov . t p i t ti it om orin . r or w lot o nim tion on t n t. Mo t o

[1] Here we will not take into account other important, but secondary factors, such as user-oriented interface personalization, interface legibility, multilevel functionality, etc.

t m r nim tion n t ot r r u u ll impl v nim tion . nim tion r not v r pl in monotonou n in tir om — om - tim irrit tin ! v nim tion r ju t littl tt r. n l r p tition o x tl t m p tt rn i r l invitin . nim tion r i r nt. lt ou t n u or t m purpo nim tion (. . n- im t lo o) t r r rom monotonou . ir Li fl vor m t m lw unpr i t l onv in lin o li .

A WICA-Based Homepage n x mpl on i r n mi w - it lo o own in i ur 2. i u o w impl m nt in t om - p o ro . om ni o ri i o 4 . wo o i r nt olor r up rimpo on t p lo o n n w p tt rn i r l into on o t m tim not r p i l t li in p rt xt lin . in t ppl t r i on p r t ML r m it i lw vi i l v n w n ot r r m r n . lt ou t i pl ov r t lo o t lo o r m in l r n i not i n it. r ultin nim tion i mu mor int r tin unpr i t l n liv t n n nim t or pr - i n nim tion n . ttri ut t i t to t u o Li t niqu .

Figure2. n mi w it lo o.

p i impl m nt tion w m o t t t llul r utom - ton ppl t u onw l i m o Li rul . ow v r t worl (impl m nt r n r itr r roun pi tur) i r two p r- ll l in p n nt ov rl ppin . t i n int r tiv ppl t w r ontrol i i v t rou li in on t xtu l lin r t r t n t ort o ox u o utton n m nu . tu l im n ion o t ri r r itr r ut in u u ll o wit pi tur roun t iz i i t t t pi tur .

l orit m impl m nt t r m t o or m in it l ul tion i ntl [2]

1. il t urr nt n r tion i i pl on t r n t n xt n r tion i pr p r on n o - r n u r n t n r pl t urr nt r n in in l t p.
2. Onl ll t t n t ir t tu r r -p int .

[2] The basic algorithm is due to Andreas Ehrencrona [5].

3. n l ul tin t num r o liv n i or o ll nowl rom pr viou ll l ul tion i u . . in t l t olumn o t urr nt ll i t mi l olumn o t pr viou ll t t tu o t l t n i or i nown n n not r l ul t .

n mi r t r o i on two p r ll l in p n nt pl in imult n ou l in t m worl . worl i ontroll v - ript t t m nt t t tiv t v routin . n t i routin i tiv t n w p tt rn o ll i in rt into on o t . t t r iv t p tt rn i l t t r n om. l o l t t r n om r t r p r m t r o t n w p tt rn t p tt rn it l it olor n it lo tion wit in t r m . p tt rn it l i l t rom li t o t r int r tin n w ll- nown un t l p tt rn t *R-Pentomino* t *H-Heptomino* n t *Pi-Heptomino.* olor i l t t r n om rom li t n in t ML l . i impl m nt tion r ult in vin x tl two olor (n two popul - tion) t n iv n mom nt ut t olor m n ivin t illu ion o in n w popul tion . t l o iv om w t un xp t vior on o t popul tion u nl n olor n t n w p tt rn.

Text Oriented Interactivity nim tion n int r t wit xt Ori nt nt r (O) 17 o t t t lw r n w t m lv . oi 6 own in i ur 3 i u n xt n ion o n not r x mpl o v lu - ommuni tion. oi provi t u r wit n int r tiv m o Li impl m nt tion t t i ontroll r -flowin t xt. w i n to r t in p r ll l to r ul r ML p rt xt v nt in ort o -pro u t to r ul r p r qu t n lw pro u in t m (l it unpr i t l) vior n m l in n w p tt rn to t worl . oi on t ot r n i i n to p r orm v riou pr n tion . n oi v riou p rlin m n i r nt t in n p r orm i r nt i t tion . i i on u in mor iv r v - v ript int r w r multipl v routin n tiv t t v ript omm n .
oi m u o t r tool ML r m v n v ript. ML r m r u or r tin p w r on p rt o t p (t pro r m or t pi tur) i t ti n on t ntl i pl in pr n lo tion w il t r t o t p n roll or n ont nt. i m t iz o t u r int r pr ti ll unlimit . v i u or t pro r m it l v ript or m nipul tin t p rt xt lin n t v - v ript int r i u to llow t t xt to ontrol t pro r m.
t xt ri t ppl t t t i i pl on t ML p n llow t row in u r to pl n l rn wit it li in on t ppropri t wor . oi ppli tion t u mon tr t t t Li t niqu n u tion l v lu to t m in r in n int r tiv n liv pro . or x mpl ou n im in n rti i l Li nt r tiv n oo w r u in t i t niqu ou n tu ll tr n orm our r in into n tiv pro . n x mpl woul i ou o not now w t i n unit in n ur l n twor i ou ju t li on t i n unit t xt n ou t t t

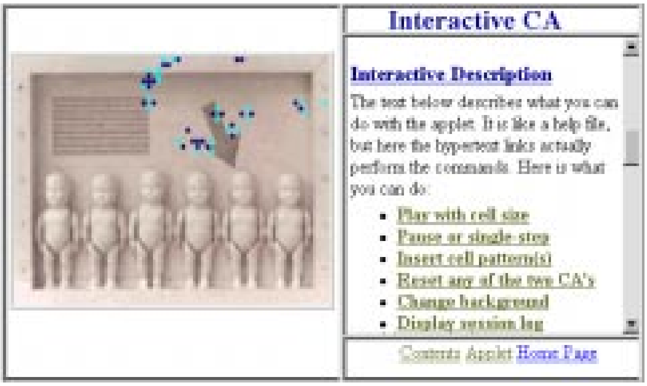

Figure3. oi w it .

orr pon in p rt o t n ur l n twor pi tur i fl in . t i w t w m n r in n int r tiv pro . O our t i i t mo t t ti p rt o it. ou n l o t in o intro u in oo r flowin t xt into runnin imul tion t .

3.2 Flocking Web Creatures

lo 7 r not r x mpl in w i Li i u ro ov r wit int r i u . lo (own in i ur 4) lon to t flo in Li r tur v ri t 19 rin wit t m t o i l t n n to ti to t r n t li -li m r nt vior w i i on w impl lo l rul . i r rom mo t ot r Li flo in (oi -t p) impl m nt tion in t rritori l n-im t t t n t ir t rritor in t intru r . n t t m t r impl m nt v ppl t . mor v n ppl t llow in ivi u l lo to n tr it n p r on lit (i lo n lo) n popul tion o lo to r n volv (lo). On n o rv v riou ppli tion o t i t -niqu . oi - l orit m n u in t nt rt inm nt in u tr (. . in t ur i r movi or nim tin torm o pr i tori ir). or n x mpl o it ppli tion to . nim tion r liz wit t i in o t niqu i mor li -li vi u ll pl in n m rt r t n tr ition l nim tion t niqu ; it i l o to r liz — on on l rn to pro r m t oi or impl u t ir ppl t.

or urt r i u in lo impli tion or l t u o ov r w t il out t ir impl m nt tion. n n r l t lo vior i ov rn two rul

– rul p i in ow to r l t to on own in ;
– rul p i in ow to r l t to tr n r .

nli mo t ot r flo in l orit m lo o not r l t to ll m m r o it ommunit ut onl to it two lo t n i or . i i w orrow

Figure4. lo w it .

rom l x ulli m li o 9 o w i lo i n nt. lo i motion ll tt to two ot r m m r (it n i or) o t flo n tri to t lo to t m.[3] lo r l t to t n i orin lo i nti in w t r t r o it own in or tr n r . t will tr n r w w il in it own t rritor or fl i tr n r w il out i o it own t rritor .

n t i lo ppl t vior p r m t r r ommon to t w ol popul tion. n i lo in t lo n i n i r nt tr it . mon t p r m t r t t n i n w n l r tion ion olli ion i - t n n m ximum p . or x mpl n i lo wit i r l r tion n p tr it will t n to t r mor rupt n will pp r mor n rvou pont n ou n in ivi u li ti ; lo wit i r ion v lu will t n to lin mor to t ommunit n will loo li on ormi t. n on i lo i i n i p or l r tion tr it t w ol roup om littl on u n i or niz . n i lo wit low n l z tr it will l t in . olor o or tr n r v . lo l lo . Lo l i lo v t r iv v- ior w il non-lo l i lo v t fli t vior. n i lo r tr n orm to t tr n r olor t r tt v n i t r t m jorit . ow v r w n m n tr n r r pr nt t lo l i lo pp r on u n o not t t m tiv l .

mo t v n o t t r v r ion i t lo ppl t w i upport volution. i tup llow m nipul tion o mor t n 30 i r nt p r m t r . n ition v r l pr - n vior t l n i n to t urr nt popul tion. ppl t l o upport t option o tt in num r r p - i ll to lo in or r to tr in ivi u l lo il . lt ou ppl t o not upport l or urit r on urr nt t tu n r ult n l-

[3] An approximate neighbor detection algorithm is used for efficiency, which is of course a crucial aspect in Web design.

w i pl in i t in orm tion r n. r non- volvin lo liv t rn ll (or until t ir n r rop to z ro) lo liv on n r tion n n r tion n w n t tr n r i n ll ill . lo volv xu ll w r lo i t n nt o two p r nt . two p r nt r l t or in to two tn ttri ut n r n t . n lo n in or lo t urin it li tim n t mor it t tt r it i . n r i lo t proportion ll to p n t i in rom proximit to n i or . it t i t-up on n il m xp rim nt wit popul tion o lo vin pr n vior or p r orm imul tion o t volution r pro tunin t r l tiv w i t o t n n r in t tn un tion.

3.3 Interactive Computer Art

lo v x mpli ow Li mo l n impl m nt to run ro t . ut o u t m or n t in u ul rom point o vi w? po itiv n w r m o t in on i rin int r tiv omput r rt w r t u r int r t wit r p i l o j t r t r t n o . rti i l int r pro r m 1 21 10 i on o v r l ppli tion o Li to omput r r p i i n. t i on rti i l n ur l n twor n volution r l orit m . t t innin o volution r ion it n r t 16 r n om im w i r ort o -im or t p int r to t rt it wor . u r n l t our o t m p r nt w i t n pro u ixt n n w in ivi u l on titutin n w n r tion. u r n zoom out o t im r ull loo t t m n o rv n tr n n int r tion in ompo ition olor t xtur orm n p r p tiv . onl p r m t r t u r n ontrol t n r tion i mut tion r t (w i ow v r n i n i r ntl or n r tion).

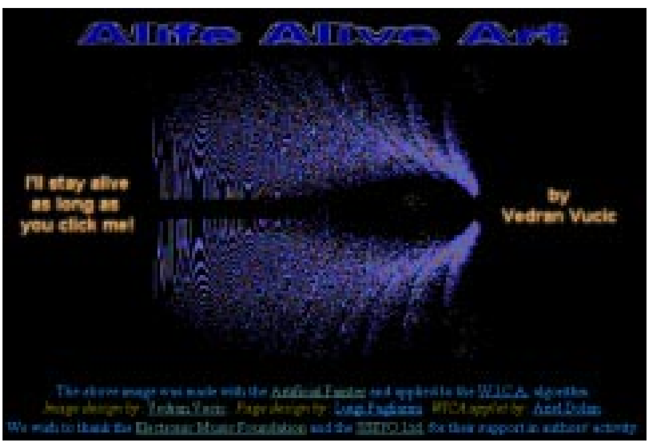

Figure5. li liv rt w it .

ppli tion o t i pro r m n n in r n u i om p 11 n t li liv rt it 12 own in i ur 5. it mon tr t oupl o point . ir t Li t niqu n ppli to r p i i n n t r or to in t o r n u i it . on t u r n int r t wit n influ n pi tur ontrollin it Li - volution. li liv rt it riv rom t rti i l int r n lo llow t u r to o o int r tin wit t t xt t t i tt to n p rt o t pi tur .

4 Conclusion

proj t urv in t i p p r o r n to i li t om o t m tin point tw n Li n t . w v n owin ll lon t p p r on n t w n nvirom nt w r rti i l r tur m up wit Li t niqu n mov . l o ow t t on n im in t r tur to v r i r nt nt wit v r i r nt un tion n prop rti .

ir tl own t n o pi r t i rtil roun to ppl n xplor Li -in pir l orit m . l troni in orm tion nvironm nt row n om mor ompl x w il t l o u r xt n rom omput r xp rt to l m nt r ool tu nt t n or o t omputin t nolo i n onl om mor trin nt in our vi w. mor t loo li n tur l liv nvironm nt t mor w mu t loo t r l livin t m or um lin in pir tion.

i l o m to t or w v oun Li t niqu (in pir livin t m) to provi num r o uit l tool t t mi t ilit t t i n o pl in int r . v own x mpl o u o u t niqu to i v pp lin t ti (in t li liv rt it n r n u i om p) m rt nim tion (in t n lo it) n l v r int r tiv rul (in t oi mon tr tion).

in ll on n l o vi w t r t tin roun or Li mo - l x mpli in t lo t m. pr mi o t i nti m t o i t r pro u i ilit o xp rim nt . Li t niqu n imul tor r o t n i ult to omp r u to t t t t n i r nt l o nviron- m nt . provi Li pr tition r wit lo l l or tor in w i t n x min t ir t ori n o oo i n .

o in u pro l m t nt i o virtu l worl on t w it m n r to t into ount t o in o ppro w v own. mo t import nt l on l rn i t in o t w n tur l nvirom nt w r to pl or ni m n oin t t on qui l r liz t t Li t niqu t t mom nt r t mo t t on or t r liz tion o io-li worl .

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Information Flocking: Data Visualisation in Virtual Worlds Using Emergent Behaviours

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Abstract. A novel method of visualising data based upon the schooling behaviour of fish is described. The technique allows the user to see complex correlations between data items through the amount of time each fish spends near others. It is an example of a biologically inspired approach to data visualisation in virtual worlds, as well as being one of the first uses of VRML 2.0 and Java to create Artificial Life. We describe an initial application of the system, the visualisation of the interests of a group of users. We conclude that Information Flocking is a particularly powerful technique because it presents data in a colourful, dynamic form that allows people to easily identify patterns that would not otherwise be obvious.

1. Introduction

1.1 Flocking & Schooling

Birds flock, fish school, cattle herd. The natural world has many examples of species that organise themselves into groups for some reason, for example to reduce predation. It has been shown [1] that many predators are "tuned" to hunting individuals, and are confused by large numbers of animals organised into a flock or school. Although the evolutionary advantages in flocks had been well characterised no simple models reproducing such behaviours had been demonstrated.

Reynolds created computer simulations of such flocks by modelling a few simple rules [2], and christened individuals that undergo such flocking "boids". Animations based upon boid-like motion have appeared in a number of Hollywood films[1].

The *emergent behaviour* of the flock is the result of the interaction of a few simple rules. In Reynolds' simulation, these were:

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[1] Examples: herds of dinosaurs in “Jurassic Park”, flocks of bats in “Cliffhanger” and “Batman Returns” and the wildebeest stampede in “The Lion King”.

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- collision avoidance
- velocity matching (flying with the same speed and direction as the others)
- flock centring (trying to fly near the centroid of one's neighbours)

These rules are sufficient to reproduce natural behaviours, particularly if a predator is treated as an obstacle. However their simplicity allows the use of such self-organised behaviour to be extended to serve a more useful purpose: data visualisation. In Information Flocking, a fourth rule is added which modifies the motion of the individuals on the basis of some similarity measure. This measure can be derived from a set of data, with each individual boid associated with a single data item. The flocking motion then becomes a means of visualising the similarities between the individual data items.

A virtual world was created to display the flocking behaviour. Initially this consists of a school of fish swimming around in 3D, but it is easily extended to include such concepts as attractive and repellent objects (which might attract or repel specific items), and predators which might act as data filters.

The initial problem to which Information Flocking was applied is that of visualising the interests of a group of people. Previously, hierarchical clustering techniques [5] have been applied to such data sets. Neural network approaches have also been used [6]. In particular, Orwig and Chen [7] have used Kohonen neural nets [8] to produced graphical representations of such data. While these representations proved to be much faster and at least as powerful as subjective human classification, they are essentially static. Information flocking is dynamic in that the fish in the simulation can change their behaviour in response to changes in the underlying data set. The output is also dynamic (the fish “swim”) which allows the human viewer to identify patterns more easily.

2. Methods

2.1 VRML

The prototype Information Flocking system was developed using VRML (Virtual Reality Modelling Language), version 2.0[2]. This is a powerful, emerging technology that allows rapid development of graphical programs. Objects in a VRML "world" can be controlled by means of a Java script. This results in a system that can produce 3D, interactive graphical simulations that can be controlled using all the features of the Java programming language. VRML is also platform independent and allows easy creation of multi-user environments. A schematic of the system is given in Fig. 1.

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[2] See the VRML Repository at http://www.sdsc.edu/vrml/ for more information on VRML.

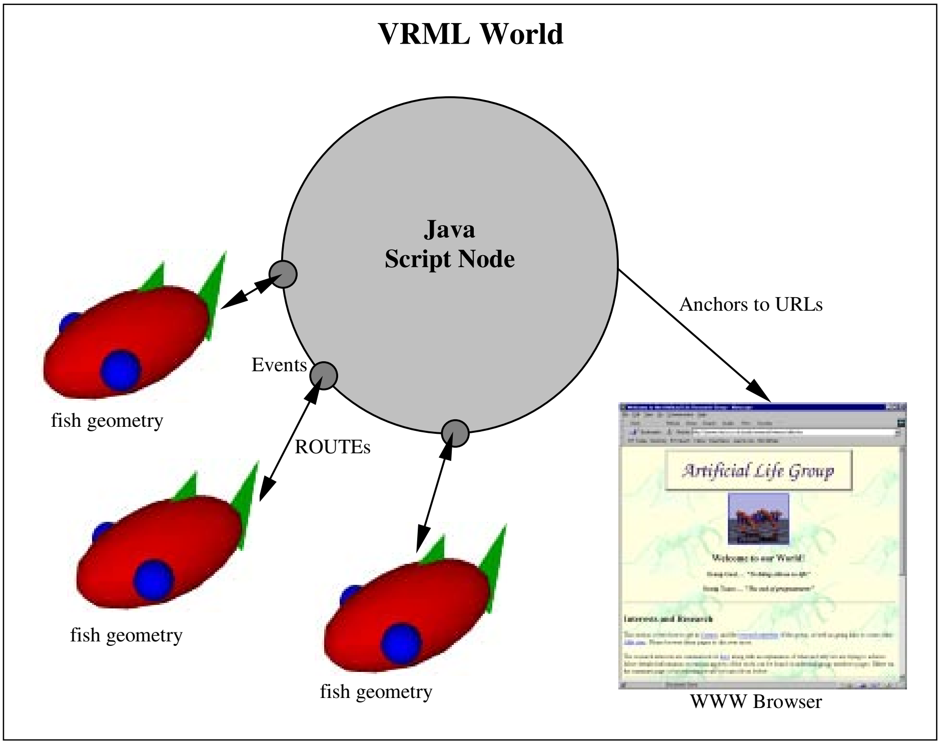

Fig. 1. Schematic of a VRML world. The world is organised hierarchically; different node types define geometry, appearance, camera views etc.. A Script node allows interfacing to a Java program. This controls the behaviour of the fish. Communication is event-driven, and events are connected by structures known as Routes. Objects (e.g. fish) can be "anchored" to URLs; thus when a fish is clicked upon, the relevant page can be opened in a normal web browser such as Netscape. A more detailed description of VRML can be found at the VRML Repository (see footnote on previous page).

2.2 Modelling Emergent Behaviour

The fish in the demonstration are initially positioned randomly. They then swim along a heading vector, which is the resultant of several component vectors, one for each of the behavioural rules. In the current system, these are:

- collision avoidance - avoid collisions with other fish if possible. The vector for this behaviour is calculated to take each individual away from its close neighbours.

- *velocity matching* - each individual tries to swim in the same direction and at the same speed as nearby fish, subject to a minimum and maximum speed.

- *origin homing* - try to swim towards the origin. This has the effect of keeping the fish on screen, and results in their swimming around in a simulated "bowl", rather than disappearing into infinity.

- *information flocking* - swim closer to fish that are similar, and further from fish that are different[3]. The vector for this is calculated as the weighted resultant of all the vectors between the current fish and its neighbours. The weights are obtained from the correlation matrix described in §2.3.

The result of these calculations is a vector representing the ideal heading for the fish in question. This ideal heading vector is averaged with the current heading to give the fish's actual new heading.

The calculation of the heading vector for a fish A is as follows:

$$\text{New heading} = w_{CA}\sum -(b_i - A) + w_{VM}\sum (C - A) + w_{OH}\sum (A - O) + w_{IF}\sum S_{ij}(b_i - A)$$

where:

w_{CA}, w_{VM}, w_{OH}, w_{IF} = weighting applied to Collision Avoidance, Velocity Matching, Origin Homing and Information Flocking behaviours respectively
A, b_i, O = position vector of fish A, fish i and origin respectively
C = position vector of the centroid of fish A's neighbours (see below)
S_{ij} = similarity of fish A and fish i.

Notes:

1. The collision avoidance component of the heading vector is repulsive, while all the other components are attractive.

2. The similarity matrix is calculated at the start of the simulation, to maximise the speed. There is no reason that it could not be calculated on-the-fly from "live" data; this would result in the fish changing their behaviour dynamically to reflect the changes in the data.

3. At each time-step, two main calculations must be performed:

   i. The matrix of distances between the fish must be recalculated. This matrix is symmetric, so in order to optimise the speed of the simulation, only half of it is

[3] The weight, w_{IF}, applied to the Information Flocking behavioural component, determines the strength of inter-fish attraction. In the "interest" data set that is used for the current demonstration, w_{IF} lies between 0.0 and 1.0, so completely dissimilar fish have zero attraction. It would be feasible for w_{IF} to be in the range –1.0 to 1.0; this would result in a more marked separation. The "interest" data set was used as obtained by the authors, without modification.

calculated and then copied into the other half (since the distance between fish *i* and fish *j* is equal to the distance between fish *j* and fish *i*!) Distances are actually stored as their squares in order to avoid large numbers of calculations of computationally-intensive square roots.

ii. The near-neighbours of each fish must be recalculated. This is based on the distance matrix described above.

Each fish can sense its environment to a very limited extent. They can "see" for a fixed distance in a sphere around them. No attempt has been made to implement directional vision; the simple spherical model was considered sufficient for our purposes. The distance that the fish can "see" can be varied; in most of our investigations so far a distance approximately equal to four body lengths has been appropriate. This point is discussed in more detail below.

Each fish can be given a colour and a label, which appears when the mouse pointer is moved over it. URLs (Uniform Resource Locators) can be specified for each fish; when this is done, clicking on the fish will open the relevant web page in a browser such as Netscape.

It should be pointed out that the choice of the fish representation was an arbitrary decision based upon ease of construction and rendering. The behaviour of birds, bees or sheep could be modelled with very little modification. Other workers, notably Terzopoulos, Tu and Grzeszczuk have presented work that concentrates on the simulation of the behaviour of real fish [3].

2.3 Data Used

The data used for the Information Flocking needs to provide weights for all possible pairwise interactions between the fish. Thus, it needs to be in the form of a square, symmetric matrix. In the current application, this is in the form of a matrix of similarities between the interests of a group of Internet users [4], but any data in the correct format could be visualised using this technique.

The colours, labels and URLs of the fish are also read in from files. In the case of the ‘interest’ data, the labels represent the interests of the individuals, and the colour of each fish represents the primary interest of that person.

3. Results

An example screenshot is shown in Fig. 2.

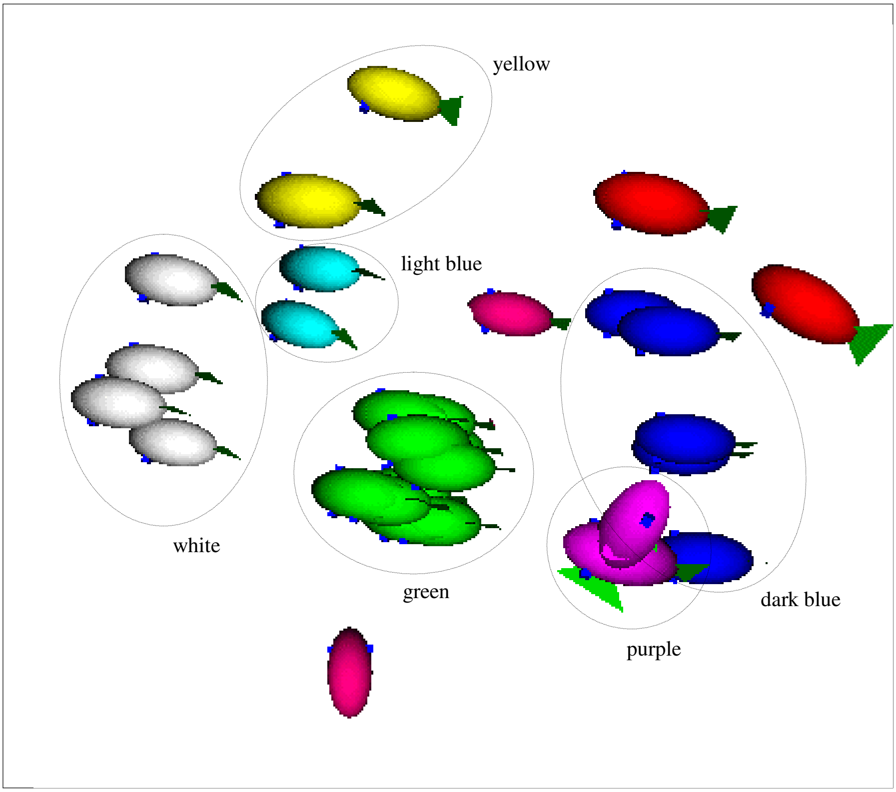

Fig. 2. Screenshot of the Information Flocking simulation. The labels represent the colours of the fish when seen on a colour monitor. Only the colours referred to in the text below are labelled. The ellipses in the figure serve only to delineate the colour groups; they do not appear in the actual simulation.

Watching the simulation for even a short period of time is very instructive. Several closely-related groups are immediately visible; the green, white and dark blue fish form small groups, indicating that the users in each of these groups have very similar interests. However, the individual groups also tend to form larger, more diffuse "supergroups"; for example the green, white, dark blue and purple fish all tend to move around in a large group, indicating a lower, but still significant, level of inter-group similarity.

Other small groups remain distinct from the main group. The light blue fish tend to exhibit markedly different behaviour, indicating that the users whom they represent have substantially different interests to the other users.

More subtle interactions can also be seen. The two yellow fish ostensibly represent people with the same primary interest, yet they do not swim close to each other. Upon further inspection, the two individuals turn out to be interested in different aspects of the same subject, which is the reason for the separation of the fish representing them.

4. Future Developments

Feedback on the prototype information flocking demonstrator described in this paper has been exceedingly positive; for this reason we are actively developing the system. Development is proceeding in three main areas:

1. Speed: currently the system runs at an acceptable frame rate (30 frames per second on a high-end PC with hardware 3D acceleration) for data sets represented by up to about 250 fish. Clearly this needs to be extended to handle data sets involving 1000 or more individuals (see note 2 below). Recent advances in VRML browsers, rendering engines and hardware graphics acceleration are also yielding considerable speed increases.

2. Data sets: we are investigating the properties of the system when applied to data sets other than the one initially used. Other correlation methods are also being tried.

3. Statistical investigations: through initial experiments with the current Information Flocking demonstrator, it appears that several factors can significantly affect the emergent behaviour. For example:

   - the weights applied to each of the component vectors in the calculation of the heading vector.

   - the distance within which the fish can detect each other

Preliminary results from some of these further developments are very illuminating. For instance, when a simulation with over 300 fish was set-up it was found that if the vision horizon was too long they formed a single, undifferentiated clump. If it was too short they never flocked but moved as individuals. There is clearly an optimal setting which leads to the formation of fluid groups, that keep partially breaking up and reforming. The suggestion here is that this phenomenon may be explained as a phase transition between a gaseous random state and a solid one, as the order parameter is changed. Clearly the system needs to be tuned into the phase transition zone to work best. Such phenomena are also seen in classical hierarchical clustering [5], and work is underway to reconcile these explanations.

As the exact values depend on all the parameter settings, and on the numbers of fish, their relative volume and that of the virtual space this could be difficult. We are

now developing a system where the fish increase or decrease their horizon depending on their 'satisfaction' - the degree to which they have found similar fish near them. Early results suggests this leads to some particularly interesting phenomena akin to courtship behaviours.

5. Conclusions

This paper has described the concept of Information Flocking. It shows that ideas in artificial life, developed to mimic biology have much more powerful applications outside the arena of simulations.

The technique is powerful because it presents data in a form which is particularly suited to the human brain's evolved ability to process information. Human beings are very good at seeing patterns in colour and motion, and Information Flocking is a way of leveraging this ability. The dynamics of the system provide a much greater degree of understanding that the initial data would suggest.

Virtual worlds with virtual organisms could have a powerful impact on the way we use and visualise complex data systems. A number of demonstrators have now been built that show these concepts in action.

Acknowledgements

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Nerve Garden: A Public Terrarium in Cyberspace

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Abstract. Nerve Garden is a biologically-inspired multi-user collaborative 3D virtual world available to a wide Internet audience. The project combines a number of methods and technologies, including L-systems, Java, cellular automata, and VRML. Nerve Garden is a work in progress designed to provide a compelling experience of a virtual terrarium which exhibits properties of growth, decay and cybernetics reminiscent of a simple ecosystem. The goals of the Nerve Garden project are to create an on-line "collaborative Artificial Life laboratory" which can be extended by a large number of users for purposes of education and research.

Introduction

During the summer of 1994, one of us (Damer) paid a visit to the Santa Fe Institute (SFI) for discussions with Chris Langton and his student team working on the Swarm simulation system [8]. Two fortuitous events coincided with that visit: SFI was installing the first World Wide Web browsers, and digital movies of Karl Sims' evolving "block creatures" [1, 7] were being viewed through the Web by amazed students (figure 1). It was postulated then that the combination of the emerging backbone of the Internet, a distributed simulation environment like Swarm and the compelling 3D visuals and underlying techniques of Sims' creatures could be combined to produce something very compelling: on-line virtual worlds in which thousands of users could collaboratively experiment with biological paradigms.

In the three years since the SFI visit, we founded an organization called the Contact Consortium [11]. This organization serves as a focal point for the development of on-line virtual worlds and hosts conferences and research and development projects. One of its special interest groups, called Biota.org, was chartered to develop virtual worlds

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using techniques from the natural world. Its first effort is Nerve Garden which came on-line in August of 1997 at the SIGGRAPH 97 conference [12].

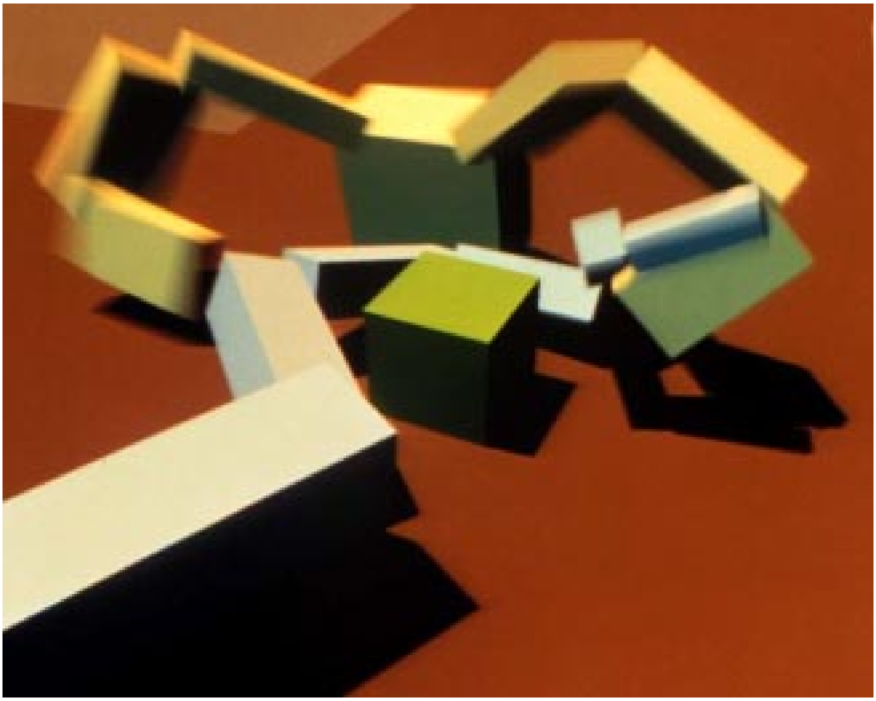

Fig. 1. View of two of Karl Sims' original evolving creatures in a competition to control a block. Iterations of this exercise with mutations of creature's underlying genotypes yielding winning strategies created a large variety of forms. Above we see a two armed grasping strategy being bested by a single armed 'hockey stick' strategy. Courtesy K Sims. See [7] for the original MPEG movies of Sims' creatures.

Three hundred visitors to the Nerve Garden installation used L-systems and Java to germinate plants models into a shared VRML (Virtual Reality Modeling Language) world hosted on the Internet. Biota.org is now developing a subsequent version of Nerve Garden, which will embody more biological paradigms, and, we hope, create an environment capable of supporting education, research, and cross-pollination between traditional Artificial Life subject areas and other fields.

Nerve Garden I: Architecture and Experience

Nerve Garden I is a biologically-inspired shared state 3D virtual world available to a wide audience through standard Internet protocols running on all major hardware platforms. Nerve Garden was inspired by the original work on Artificial Life by Chris

Langton [3], Tierra and other digital ecosystems by Tom Ray [2,3] and the evolving 3D virtual creatures of Karl Sims [1]. Nerve Garden sources its models and methods from the original work on L-systems by Aristide Lindenmayer, Przemyslaw Prusinkiewicz and Radomir Mech [5, 6] and the tools from Laurens Lapre [10].

Fig. 2. Lace Germinator Java client interface showing the mutator outputs on the left, the growth and naming interfaces at the bottom with a plant production visualized in the main window.

The first version, Nerve Garden I, was built as a client-server system written in the distributed Java language. The client program, called the Germinator (figure 2), allowed users to extrude 3D plant models generated from L-systems. The simple interface in the Java client provided an immediate 3D experience of various L-system plant and arthropod forms. Users employed a slider bar to extrude the models in real time and a mutator to randomize production rules in the L-systems and generate variants on the plant models. Figure 3 shows various plant extrusions produced by the Germinator, including models with fluorescences. After germinating several plants,

the user would select one, name it and submit it into to a common VRML 2.0 scenegraph called the Seeder Garden.

Fig. 3. Plant models generated by the Germinator including flowering and vine like forms. Arthropods and other segmented or symmetrical forms could also be generated.

The object passed to the Seeder Garden contained the VRML export from the Germinator, the plant name and other data. The server-based Java application, called NerveServer, received this object and determined a free “plot” on an island model in a VRML scenegraph. Each island had a set number of plots and showed the user the plot his or her plant could be placed by moving an indicator sphere operated through the VRML external authoring interface (EAI). “Cybergardeners” would open a window into the Seeder Garden where they would then move the indicator sphere with their plant attached and place it into the scene. Please see an overview of the client-server architecture of Nerve Garden I in figure 4.

Various scenegraph viewpoints were made available to users, including a moving viewpoint on the back of an animated model of a flying insect endlessly touring the island. Users would often spot their plant as their bee or butterfly made a close

approach over the island (figure 5). Over 10MB of sound, some of it also generated algorithmically, emanated from different objects on the island added to the immersion of the experience. For added effect, L-system based VRML lightening (with generated thunder) occasionally streaked across the sky above the Seeder Garden islands. The populated seeder island was projected on a large screen at the Siggraph hall which drew a large number of visitors to the installation.

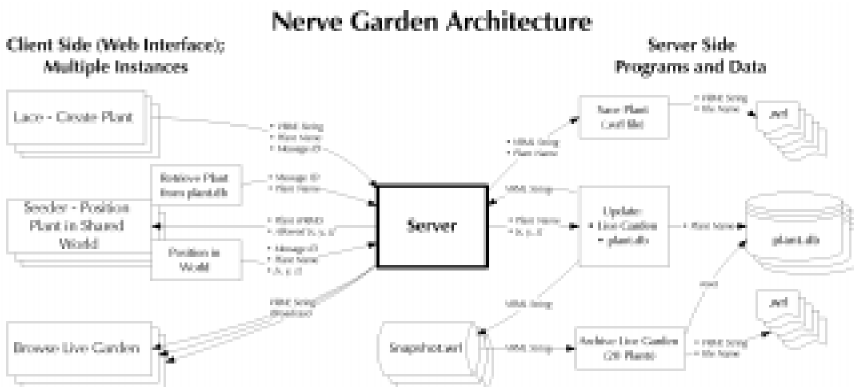

Fig. 4. Nerve Garden I architecture detailing the Java and VRML 2.0 based client-server components and their interaction.

NerveServer permitted multiple users to update and view the same island. In addition, users could navigate the same space using standard VRML plug-ins to Web browsers on Unix workstations from Silicon Graphics, PCs or Macintosh computers operating at various locations on the Internet. One problem was that the distributed L-system clients could easily generate scenes with several hundred thousand polygons, rendering them impossible to visit. We used 3D hardware acceleration, including an SGI Onyx II Infinite Reality system and a PC running a 3D Labs Permedia video acceleration card to permit a more complex environment to be experienced by users.

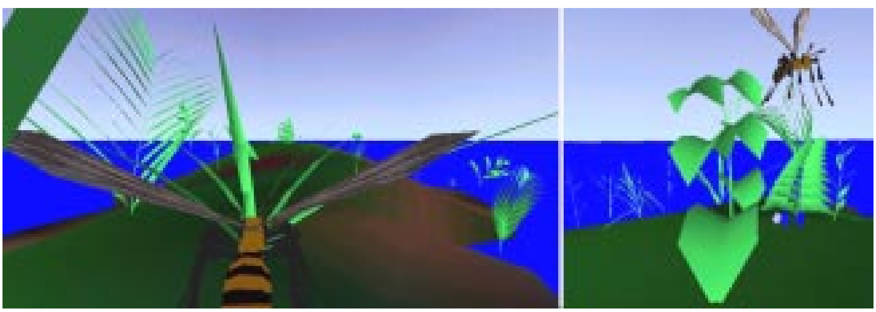

Fig. 5. Flight of the bumblebee above a Seeder Garden

In 1999 and beyond, a whole new generation of 3D chip sets on 32 and 64 bit platforms will enable highly complex 3D interactive environments. There is an interesting parallel here to Ray's work on Tierra [2,9], where the energy of the system was proportional to the power of the CPU serving the virtual machine inhabited by Tierran organisms. In many Artificial Life systems, it is not important to have a compelling 3D interface. The benefits to providing one for Nerve Garden are that it encouraged participation and experimentation from a wide non-technical group of users. The experience of Nerve Garden I is fully documented on the Web and several gardens generated during the SIGGRAPH 97 installation can be visited on-line with a VRML 2.0 equipped web browser [12].

What was Learned

As a complex set of parts including a Java client, simple object distribution system, a multi-user server, a rudimentary database and a shared, persistent VRML scenegraph, Nerve Garden functioned well under the pressures of a diverse range of users on multiple hardware platforms. Users were able to use the Germinator applet without our assistance to generate fairly complex, unique, and aesthetically pleasing models. Users were all familiar with the metaphor of gardens and many were eager to "visit their plant" again from their home computers. Placing their plants in the VRML Seeder Gardens was more challenging due to the difficulty of navigating in 3D using VRML browsers. Younger users tended to be much more adept at using the 3D environment.

In summary, while a successful user experience of a generative environment, Nerve Garden I lacked the sophistication of a "true -Life system" like Tierra [2,9] in that plant model objects did not reproduce or communicate between virtual machines containing other gardens. In addition, unlike an adaptive L-system space such as the one described by Mech and Prusinkiewicz [6] the plant models did not interact with their neighbors or the environment. Lastly, there was no concept of autonomous, self replicating objects within the environment. Nerve Garden II, now under development, will address some of these shortcomings, and, we hope, contribute a powerful tool for education and research in the ALife community.

The Next Steps: Nerve Garden II

The goals for Nerve Garden II are:

- to develop a simple functioning ecosystem within the VRML scenegraph to control polygon growth and evolve elements of the world through time;
- to integrate with a stronger database to permit garden cloning and inter-garden communication encouraging cross pollination between islands;

- to integrate a cellular automata engine which will support autonomous growth and replication of plant models and introduce a class of virtual herbivores ("polyvores") which prey on the plants' polygonal energy stores;
- to stream world geometry through the transmission of generative algorithms (such as the L-systems) rather than geometry, achieving great compression, efficient use of bandwidth and control of polygon explosion and scene evolution on the client side;

Much of the above depends on the availability of a comprehensive scenegraph and behavior control mechanism. In development over the past two years, Nerves is a simple but high performance general purpose cellular automata engine written as both a C++ and Java kernel [13]. Nerves is modeled on the biological processes seen in animal nervous systems, and plant and animal circulatory systems, which all could be reduced to token passing and storage mechanisms. Nerves and its associated language, NerveScript, allows users to define a large number of arbitrary pathways and collection pools supporting flows of arbitrary tokens, token storage, token correlation, and filtering. Nerves borrows many concepts from neural networks and directed graphs used in concert with genetic and generative algorithms as reported by Ray [3], Sims [1] and others.

Nerves components will underlie the Seeder Gardens providing functions analogous to a drip irrigation system, defining a finite and therefore regulatory resource from which the plant models must draw for continued growth. In addition, Nerves control paths will be generated as L-system models extrude, providing wiring connected to the geometry and proximity sensors in the model. This will permit interaction with the plant models. When pruning of plant geometry occurs or growth stimulus becomes scarce, the transformation of the plant models can be triggered. One step beyond this will be the introduction of autonomous entities into the gardens, which we term "polyvores", that will seek to convert the "energy" represented by the polygons in the plant models, into reproductive capacity. Polyvores will provide another source of regulation in this simple ecosystem. Gardens will maintain their interactive capacity, allowing users to enter, germinate plants, introduce polyvores, and prune plants or cull polyvores. Gardens will also run as automated systems, maintaining polygon complexity within boundaries that allow users to enter the environment.

Example of a NerveScript coding language

```
spinalTap.nrv:
DEF spinalCordSeg Bundle {
-spinalTapA-Swim-bodyMotion[4]-Complex;
-spinalTapB-Swim-bodyMotion[4]-Complex;
}
```

We expect to use Nerves to tie much of the above processes together. Like VRML, Nerves is described by a set of public domain APIs and a published language, NerveScript [13]. Figure 6 lists some typical NerveScript statements which describe a two chain neural pathway that might be used as a spinal chord of a simple swimming fish. DEF defines a reusable object `spinalCordSeg` consisting of input paths `spinalTapA` and `spinalTapB` which will only pass the token `Swim` into a four stage filter called `bodyMotion`. All generated tokens end up in `Complex`, another Nerve bundle, defined elsewhere.

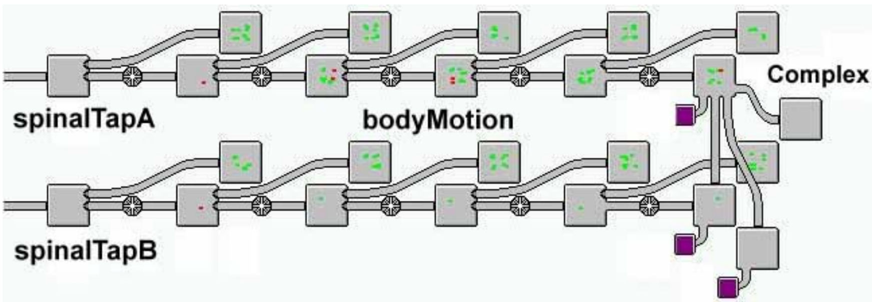

Fig. 6. Nerves visualizer running within the NerveScript development environment. In the VRML setting, the pathways *spinalTapA* and *spinalTapB* are fed by *eventOut* messages drawn out of the scenegraph while the Nerve bundles generate *eventIns* back to VRML using the EAI. *BodyMotion* are a series of stages where filters draw off message tokens to drive simulated musculature on the left and right hand side of the VRML model, simulating a swimming motion. Message tokens that reach *Complex*, a kind of simple brain, trigger events in the overall simulation, and exporting messages back into the external pool.

Figure 6 shows the visualization of the sample NerveScript code running in the NerveScript development environment. We are currently connecting Nerves to the VRML environment, where it will be possible to visualize the operation in 3D. Nerves is fully described at the web address referenced at the end of this paper.

Goals and Call for Participation

The goals of the Nerve Garden project are to create an on-line "collaborative A-Life laboratory" which can be extended by a large number of users for purposes of education and research. We plan to launch Nerve Garden II on the Internet and look forward to observing both the user experience and, we hope, the emergence of complex forms and interactions within some of the simple garden ecosystems. The Contact Consortium and its Biota.org special interest group would welcome additional collaborators on this project.

Acknowledgments

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9. Tom Ray's Tierra is fully described at http://www.hip.atr.co.jp/~ray/tierra/tierra.html
10. Laurens Lapre's L-parser L-system software tools and examples can be found at: http://www.xs4all.nl/~ljlapre/
11. Full background on the goals and projects of the Contact Consortium are at http://www.ccon.org and its special interest group, Biota.org are at http://www.biota.org
12. Nerve Garden I can be entered at http://www.biota.org/nervegarden/index.html with a suitable VRML 2.0 browser installed.
13. The Nerves home page, with language specification, examples and downloads is at: http://www.digitalspace.com/nerves/

A Two Dimensional Virtual World to Explain the Genetic Code Structure ?

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Abstract. In this study, we introduce a remarkable squared tiling of the plan whose characteristics meet in many points those of the genetic code: same number of structural levels (3), same number of elements at each level (4, 64 and 20), same relationships between the elements of the different levels. To conclude, we formulate one hypothesis to explain these results and consequently we propose new ways of research in Artificial Life, but also in structural molecular biology.

1 Introduction and Purpose

In Artificial Life studies, Mathematics and mathematical tools are important to explore and to experiment (by means of computer simulations) the behaviour and the fundamental structures of artificial living systems.

In real living systems studies, biological experiments are essential. In this domain, some recent experiments led by James Ferris (in collaboration with Leslie Orgel of the Salk Institute) show the importance of mineral surfaces[1] and – more precisely – the importance of geometrical constraints in the early stages of bio-molecular development (i.e. at the origin of life): mineral surfaces restrict the elementary molecular movements into a weak number of particular directions and consequently favorize the molecular polymerization (and polycondensation) processes on these surfaces [1].

Purpose: we propose to study, in a virtual mathematical plan, i.e. in a *two dimensional virtual world*, the consequences of geometrical constraints that have been observed in the real world (physico-chemical restriction of the directions of molecular movements).

[1] The hypothesis of the origin of life on mineral surfaces had remained, longtime, without determining clue. Now, the experimental works of James Ferris and al. bring some fundamental and decisive elements to satisfy to this hypothesis: *montmorillonite* surface for nucleotides polymerization (ImpA) and *illite* and *hydroxylapatite* surfaces for amino acids polymerization (glutamic and aspartic acids).

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2 Simplest Tiling of the Ideal Mathematical Plan

2.1 Tiling by Squares Requires the Weakest Number of Tiled Directions

In the ideal mathematical plan, which is the equivalent representation of an elementary bio-molecule?

In response, we can choose an elementary piece of the plan surface: for example, a polygonal tile. To link these artificial bio-molecules (the linking of tiles is similar to a polymerization process), it is necessary to be able to pave the plan with the same (or identical) regular polygonal tiles.

Only three types of regular polygon can tiled the plan: equilateral triangle, square or regular hexagon (see Fig. 1). Among these possibilities, the simplest is the tiling by squares: it requires the weakest number of tiled directions and satisfies to the purpose of this study. Accordingly, we choose the tiling by squares.

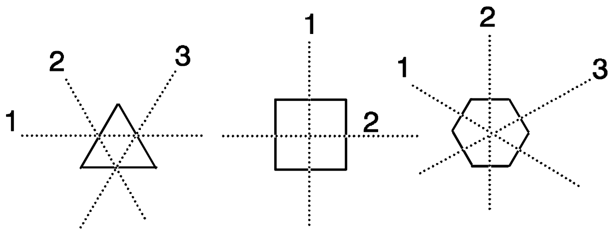

Fig. 1. The three tilings of the plan by identical polygons: equilateral triangles, squares or regular hexagons. The simplest is the tiling by squares: only two tiled directions are required in this case (three tiled directions are required in the other cases).

2.2 Simplest Tiling and Lowest Number of Squares

In biological world, *diversity* is everywhere. Life, into many different forms, is *diversity* in action. Also, we must introduce some minimal *diversity* in the tiling process. In this goal, we choose to tile the plan with the lowest number of all different squares. This choice corresponds to a *simple perfect squared square of lowest order* (see Fig. 2). It is the most economic tiling possible and its mathematical form is *uniqueness*. As a result of graph and combinatorial theories, this economic tiling has been found by A.J.W. Duijvestijn [2].

To obtain the *first generation square* (the most external and integrative square of length 112), we add *twenty different squares* to the first square or *germ* (the most inside and little square of length 2). And so on, all along the successive *generation squares*... It is a *russian doll* process: to obtain a new *generation square*, or new *integron*, we add 20 new squares to the former *generation*

square, or former *integron*. The properties of these mathematical *integrons* are analogous to the properties of the *integrons* defined by F. Jacob for the living systems [3].

Fig. 2. An Artificial Life *integron*: the simplest tiling of a square by the lowest number of all different squares.

3 A Set of Analogies Between the Simplest Tiling of the Ideal Mathematical Plan and the Universal Genetic Code

The simplest tiling, or *integron*, showed Fig. 2, is an *asymmetrical* figure. This figure marks the four directions of the plan: Up (U), Down (D), Left (L) and Right (R): i.e. a *four* letters alphabet in relation to the four sides of the asymmetrical figure. It exists also a *twenty* letters alphabet: the set of the twenty new squares added at each new generation. Between these two alphabets (the *first* of *four* letters and the *last* of *twenty* letters), it exists an *intermediate* alphabet. The *sixty-four* letters of this intermediate alphabet are the sixty-four elementary segments of the simplest tiling.

With the same number of alphabets (3) and the same numbers of letters in these alphabets (4, 64 and 20), the structure of the universal genetic code (see Fig. 3) is *similar* to the structure of the simplest tiling. The *first* alphabet of the genetic code: the *four nucleotides* Uracil (U), Cytosine (C), Adenine (A) and Guanine (G). The *intermediate* alphabet: the *sixty-four codons*. And the *last* alphabet: the *twenty amino acids* (to make the proteins).

1st • 2d •	U	C	A	G	3d •
U	Phenylalanine Phenylalanine Leucine Leucine	Serine Serine Serine Serine	Tyrosine Tyrosine Stop Stop	Cysteine Cysteine Stop Tryptophan	U C A G
C	Leucine Leucine Leucine Leucine	Proline Proline Proline Proline	Histidine Histidine Glutamine Glutamine	Arginine Arginine Arginine Arginine	U C A G
A	Isoleucine Isoleucine Isoleucine Methionine	Threonine Threonine Threonine Threonine	Asparagine Asparagine Lysine Lysine	Serine Serine Arginine Arginine	U C A G
G	Valine Valine Valine Valine	Alanine Alanine Alanine Alanine	Aspartic acid Aspartic acid Glutamic acid Glutamic acid	Glycine Glycine Glycine Glycine	U C A G

Fig. 3. The universal genetic code for the translation of the 64 codons into the 20 amino acids. A codon is a mRNA word of three letters among four mRNA bases or nucleotides (U (Uracil), C (Cytosine), A (Adenine) and G (Guanine)): first (1st), second (2d) and third (3d) letters.

Now, we define a set of *"at least – at most"* rules, or **existence and association rules**, to specify the relationships between the 64 elementary segments and the 20 squares.

Each square (among the 20 squares) is bounded by β elementary peripheral segments: $4 \leqq \beta \leqq 7$ (see Fig. 2). **Existence or *"at least"* rule:** to exist, each square (by analogy, each amino acid), must depend on ***one*** of its β bounded segments (by analogy, of *one* codon). **Association or *"at most"* rule:** each square cannot depend on the totality of its β bounded segments. At the most, it depends on $(\beta - 1)$ bounded segments: it is the only one manner to establish some minimal *association links* within the unified simplest tiling structure.

By application of these rules, we have found the relationships showed Fig. 4. This figure exhibits some remarkable analogies with the genetic code. For example, the analogies that exist between the squares of length 35, 17 and 25 and the amino acids arginine, serine and leucine.

There are only three squares (35, 17 and 25) to have the highest value of β ($\beta_{max} = 7$). At the most, each of these three squares depends on 6 bounded segments ($(\beta_{max} - 1) = 6$). In the genetic code, this value (6) corresponds to the highest number of codons that code to one amino acid. And there are only three amino acids in this case: arginine, serine and leucine...

In the genetic code, arginine and serine are *adjacents* (i.e. in the same box of the AGX codons), and leucine is *alone*. In the simplest tiling, we have some similar relative positions: squares 35 and 17 are *adjacents* and the square 25 is *alone*...

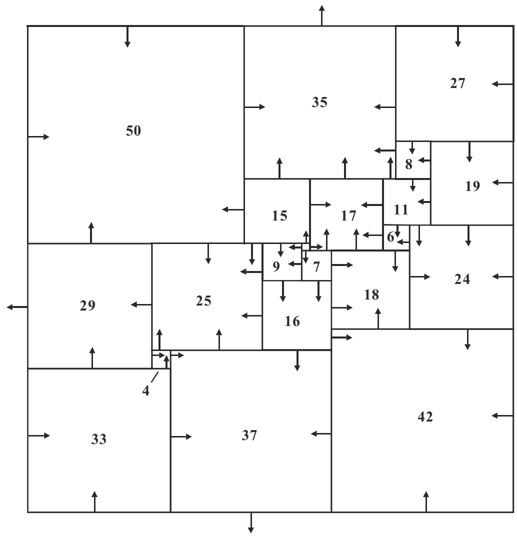

Fig. 4. Each arrow indicates a relationship between one particular bounded segment and one particular square. In the genetic code, it exists a similar relationship between one particular codon and one particular amino acid. The three outside arrows correspond to the three *Stop* codons.

4 Conclusions

4.1 How to Explain the Set of Analogies Between the Simplest Tiling of the Ideal Mathematical Plan and the Universal Genetic Code?

The results obtained and their precision lead to ask the question of a cause–to–effect relationship between the structure of the simplest tiling and of the genetic code.

How to explain the links between the mathematical elements of the 2D simplest tiling (bounded segments and squares of an unified mathematical form that is *independent* of all matter substrates) and the particular 3D molecular substrates of the genetic code (mRNA codons and amino acids)?

An answer can be found in a set of two dual graphs[2] that is the mathematical basis of the simplest tiling: a first Up–Down graph[3] links the horizontal opposite Up and Down sides of the Fig. 2, a second Left–Right graph links the vertical opposite Left and Right sides of the Fig. 2. The first graph has 11 vertices

[2] More precisely, two dual 3-connected planar graphs.

[3] Every horizontal line of the simplest tiling corresponds to a *vertice* of the Up–Down graph, and each square (between two successive horizontal lines) corresponds to an *edge*. Every vertical line of the simplest tiling corresponds to a *vertice* of the Left–Right graph.

and 22 edges. The second graph has 13 vertices and 22 edges. These graphs are isomorphic to convex polyhedra. Accordingly to the Euler formula[4]: the first polyhedron has 11 vertices and 13 faces[5] (10 triangles, one quadrilateral polygon, 2 pentagons); the second has 13 vertices and 11 faces[6] (4 triangles, 4 quadrilateral polygons, 2 pentagons and one hexagon).

In [4], it is suggested that the first genetic coding system can be started from specific interactions between two complementary 3D molecular substrates.

From an optimal space filling point–of–view (to favorize chemical interactions and to minimize energy), we think that the two unknown 3D molecular substrates have the same structures that the two previous dual polyhedra, and we propose to research the bio-molecules that could correspond (*new way of research*).

4.2 Some Propositions for New Ways in Artificial Life Research

The simplest tiling of this study, or *integron*, shows the emergence of an hierarchy of components (complexification process) and may be a potential source of new ideas (or open ways) in Artificial Life research:

- New rules for programming cellular automata... For instance, in a "particular" array (i.e. the *integron* of the Fig. 4 and its successive generations) with a rule that uses the *arrows* (to specify the authorized displacements) and works *differently* in each of the 20 squares of the Artificial Life *integron*...
- Which is the equivalent simplest tiling, or paving, of an other space? In other words, which is the equivalent genetic code of this other space? In spaces of dimension[7] $\geqq 3$? In non euclidean spaces? Life "as it could be"... Life is it an exclusive property of the euclidean space?
- Cross fertilization between the Artificial Life *integron* and the *arithmetical relator* language [5]. *Arithmetical relator* can express the world in structural levels (a quadratic form express the adaptation of the natural system to its environment). Artificial Life *integron* is also expressed by a quadratic form. The *integron* (see Fig. 4) presents a set of particular symetries: we think that the *arithmetical relator* – associated to the semisimple Lie algebra – can be an useful tool to study these symetries.

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[4] $V + F = E + 2$, where V is the number of vertices, F the number of faces and E the number of edges.

[5] Generally, non regular polygonal faces.

[6] Ibidem.

[7] The simplest paving of a cube, by all different cubes, is not possible.

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Grounding Agents in EMud Artificial Worlds

nton o rt r h nt m rgu h`l our nt

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Abstract. This paper suggests that in the context of autonomous agents and generation of intelligent behavior for such agents, a more important focus should be held on the symbolic context that forms the basis of computer programs. Basically, software agents are symbolic entities living in a symbolic world and this has an effect on how one should think about designing frameworks for their evolution or learning. We will relate the problem of symbol grounding to that of sensory information available to agents. We will then introduce an experimental environment based on virtual worlds called EMuds, where both human and artificial agents can interact. Next, we show how it can be applied in the framework of multi-agent systems to address emergence based problems and report preliminary results. We then conclude with some ongoing and future work.

Keywords: autonomous agents, symbol grounding, virtual worlds.

1 Introduction

h lopm nt o rtu l orl pro n m n to r pr nt n orm t on tor or on omput r . n r nt r mu h ort h n ot to mpro ng th o r ll n or r hn o u h orl to th n t o hum n u r . h h m nl n mpl m nt through th lopm nt o tt r r n r ng lgor thm ffi nt gr ph l ng n th u o n m t on 1 or oun 12 . n p r ll l toolk t m t pro ng l t or rtu l r l t mpl m nt t on (r l or tr ut) h n pro to ol t n r z t on u (or x mpl 14).

n ontr t ork o u ng on rtu l orl n th m l h l to n lopm nt r h ng th l o rt l nt ll g n or rt l l h r rtu l orl r n n ronm nt or th g nt un r tu . t p l nt gr t on o th t p oun n h r rtu l r l t toolk t omp t l th l ngu g or th tu o mult g nt t m l l .

Our ork nt r th r m ork tu ng g nt l ng n rtu l orl n tr ng th mport n o u h gn or n rt l nt ll g n ( ). n ronm nt u mpl t xt rtu l orl n p r rom mult u r g m ll u th t h n r n . h tup llo or r h l l o nt r t on t n hum n rt l g nt n th n ronm nt pro ng on gur t on ll u t to t t rt l g nt h or ho n n 1 .

J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 193–204, 1998.

2 Artificial Intelligence and the Grounding Problem

h l o rt l nt ll g n torn t n th l l top o n p pro h n n r ottom up m tho olog . h g p or g n t ng n orm o th m n o pro l m h l to mport nt lopm nt th n h p r gm h l n r llo ng or un t on o m tho .

2.1 State of the Art

n l l ogn t on on r th p t to orm n m n pul t nt rn l r pr nt t on or mo l o th orl (th u u l m t phor or m n n th p r gm th omput r . . m ol pro ng) 9 . h l to th u o rul t m ppl ng tr n orm t on o r m ol th t h gn t on th n r pr nt t on o pro l m om n. Su h t m ho mpr p r orm n o r p t k n pro goo r m ork or h gh l l r on ng ut h h gh n t t to nt rn l lur o u ompon nt nnot ppl to n pro l m out o th r r pr nt t on n g n r ll o not l up rom pro l m to mor g n r l on . h h n u um un r t o g n r l pro l m th *frame problem* 21 13 h r l l t m l to xt n or pt th r nt rn l r pr nt t on n th *symbol grounding problem* 11 2 h r l l t m l to r l t th r m ol r pr nt t on to th r n or n orm t on.

On th oth r h n th n m tho olog t k mor m t r l t ppro h n l ng n "gro " m n rom l m nt r nt r t ng un t on l t n n nt ll g n n g nt p t to nt r t th t n ronm nt 16 . hu n on rn th g nt pt ng th r h or to u omp t n n n n ronm nt through l rn ng or olut on. rom th pro l m ol ng po nt o th l to ro u t pt ult tol r nt lgor thm . h o n o th ppro h ng th t th o not h op t m l olut on n h n u h olut on x t th r nt rn l ork ng u u ll ffi ult to un r t n n th t u h t m pro th r u uln n ol ng ro ot t k n n m n ronm nt (u h o t l o n) mu h ork t ll h to n t n or r to t kl mor ompl x t k .

n on lu on h r l l l to r l t m ol r pr nt t on to n or n orm t on (th groun ng pro l m) n u "groun ng h poth " to u l t m rom n or n orm t on 2 3 ut l to pro u t m p l o r on ng (th houl ll th *reverse grounding problem*). Wh l n h th hop o ng ompl x h or (omp r l to tho pro u r on ng) m rg rom th nt r t on o mpl un t on l t l th t th r g ng pro l m n tt r r t rt ng o th p r pt on o h gh r l l th n th t u u ll u . ll ho th mpl th u o mul t on n m ol rtu l orl t rt ng po nt or th gn o utonomou g nt .

2.2 Embodiment

r t on ll ppro h to ol ng th groun ng pro l m h pt ottom up p r p t to h h h r h r t uppo th t m n ng to om ntr n to omput r progr m (oppo to p r t l nk to hum n nt rpr t t on) u h progr m ll h to lop t un r t n ng rom n or n orm t on. W ll th th groun ng h poth n h t qu t on th l l t h h th h poth n t ll ppl .

o t ogn t n r ugg t u ng r pr nt t on p rt o ho m ol r nt th n or p r pt n th ph l orl . . groun m ol . N on th oth r h n u th on pt o m o m nt 23 to on r g nt l nk to th ph l orl through n or motor nput/output (n th ro ot n) thout g ng n tr t n t l mo l o th orl to th r g nt (l o 3). h ph l m o m nt th n on r th on h h to tr g n r t ng nt ll g nt h or. ut th l to rg ng on t on out th on pt o m o m nt h n n g nt tu t n n rt l n ronm nt n t n m o g nt or o th on pt o m o m nt onl ppl to g nt onn t to th r l orl ? h r r t o m n r on or th r n o op n on.

r t th t mul t n ronm nt l m n t th ompl x t oun n th r l orl l m t ng th mount o n orm t on th t n p r n g nt. h pp r nt no oul nt l or qu r ng th l t to t ngu h t n th r l nt n th rr l nt n orm t on n th g nt n ronm nt ll l rn ng to pt n p r orm n r ng o tu t on . o th o j t on propon nt o mul t on t t th t th r no un m nt l r n t n p r ptu ll groun ng n g nt n n rt l n ronm nt or n th r l orl n th t th p rtur t on to th n or u to th r l orl r hn o n orm t on or ompl x t n on r r n om or ll pr t l purpo n thu r pl p u o r n om gn l up r mpo on n g nt n or nput.

S on th t n g nt ol n n rt l n ronm nt m ght n r l to r l t to th r l orl u t ll too t ghtl l nk th t “tutor l” orl to l to g n r l z h or or r l orl op r t on. h o j t on r rom th th t ollo ng tur n n r l n t on th or 23 th tru tur l oupl ng n u th m o m nt o n g nt n n n ronm nt n t ogn t on thu m ngl pr nt ng th nt gr t on o u h n g nt n n n ronm nt or th r l orl . h t r m n op n lthough m n uthor no pt th o mul t m o m nt. tu ll l th t n g nt oul groun n n rt l n ronm nt n llo to ol uffi ntl ompl x r l t on h p th t n ronm nt th oupl ng n u oul llo u h n g nt to ntro u nto n n ronm nt *through* t o n n ronm nt thout rupt ng t un t on ng. h l u to ugg t th t th m o m nt o n g nt n rtu l orl n t nt l or t to lop nt ll g nt h or n th t th r on or th l nk th th t p o n or n orm t on o t r g nt n p r .

2.3 Sensory Information

W th th ottom up ppro h to u l ng g nt om th l ng th t u h g nt r n tur ll groun n houl thu h th ttr ut to lop ogn t pro or th r rom th n or po nt o mu h p rt o th orl hum n r . h h ntl not n ho n to tru (to th) n l on o th r on n oun n k ng m l r qu t on th t po . N g l n h rt l "Wh t t l k to t?" 19 . lthough o not h to l nto th x t n o qu l th qu t on "Wh t t l k to omput r lgor thm?" om to m n n h nt th t h t r n or pp r tu n rt l g nt qu pp th h p r pt on ll r m n pur l m ol n n tur . h r gr tl th th p r pt on l l to l ng org n m n th ph l orl .

lthough hum n ng r groun n th ph l orl th r n llo ng th m to g m n ng to tr t on pt t houl r t tt mpt to groun omput r t m n th r o n m ol orl . W l th t m n ng trongl root n th t p o n or n orm t on l l to n nt t n th r n no qu l nt o n tur l n n o t r g nt. hu un r th h poth th t m n ng n om ntr n to progr m u h progr m ll h to l to g m n ng to m ol nt n m ol t rm or g ng m n ng to m ol ll tr n l t ph l nt . Our ppl t on ll on ntr t on m k ng l l r h m ol orl h r g nt n p r n orm t on o th r o n n tur th t o m ol t p n ntu ll th ph l orl through th orl th r groun n. n th t our ppl t on pro r m ork or mul t m o g nt .

3 EMuds

on th o pt ng g nt p l o m ol l l p r pt on h lop n ppl t on pro ng rtu l orl n h h g nt n nt r t. h ppl t on t k n p r t on rom nt rn t g m ll u or th r hn o t on th llo n xpl n th pr n pl on h h u un t on or r ng th gn o n u .

3.1 What Is a Mud?

h ron m t n or ult r ung on. u r nt rn t omput r g m h h r lop ollo ng th pr n pl o rol pl ng g m . n u h g m th pl r t k up th rol o h r t r n n n nt orl h r th t n pur u t o go l th t h n t to th m th gn r o th g m tor l n . h m n nt r to u h g m to o r th orl n nt th gn r or oth r pl r n nt r t th th r tur th t popul t u h orl u u ll th th m o ol ng n n gm . u t k th nto th omput r orl tt ng up n rt l n ronm nt (orl) h r pl r n onn t t ln t on n r t th t on o

h r t r th n th t n ronm nt. hrough th h r t r th pl r n th n l rtu l l n th n ronm nt l ng to hum n o l nt r t on r n or mpl xplor th orl n nt r t th omput r ontroll r tur .

3.2 What Is an EMud?

u t n or olut on r . n u n n t n o th u ppl t on g n p orl tup. h r n m n u n th r l m tl num r o rtu l orl th t n g n n n t l z t on or th ppl t on h t n t xp r m nt n ronm nt.

o g r pt on o th ppl t on tru tur t n r to un r t n om t rm u to p k o n u . h n n u h t o ompon nt on h h tot ll r on gur l t rtu l orl th on h h o th n th ppl t on th rul or n m olut on o th rtu l orl . h rtu l orl m o *loci* (pl) *elements* (tu t "th ng ") n *exits* r ng l nk rom on lo u nto noth r llo ng l m nt to mo n th orl n n ng t topolog . l m nt om n m n orm t p ll th r *objects* *creatures* (utonomou g nt) or *player-characters* (hum n g nt). Not th t l m nt m t on ll lo n h h th r ll *containers.* ll o th l m nt n lo r r n n n t l z t on l th t mu t pro th u r n th t h ll n th tt ng or th rtu l orl n h h n xp r m nt n t k pl . h th orl ol ontroll th ppl t on h h n num r o *skills* th t l m nt n ppl to th n ronm nt th k ll houl on r r fl t ng th l go rn ng olut on n th rtu l orl . r l m nt h t o k ll th t r th t on h m un rt k . o t k n x mpl uppo th orl hou . n th hou th r r room l r r h ll t . th r th lo . h l m nt n th hou oul t l ook u t (ont n r) th t (r tur) ou (pl r h r t r). h t h th k ll o mo ng p t oor (x t) t ng n purr ng. ou oul h th k ll o op n ng oor p k ng up oth r l m nt n o on. h orl oul r n n t l z t on l o th orm n n gur 1.

Wh t r m n to n ho th l m nt hoo to ppl th r k ll . h ppl t on n orpor t ontrol t m th t n o t n ontrol un t on to n l m nt pro th t th un t on h n nt r p l o nt rpr t ng m g nt th n ronm nt to th l m nt n p l o n ng omm n m g to th l m nt. ontrol lgor thm mu t pro gr mm plug n n th m hum n pl r h to un r t n m g rom th u h n onn t ng to t t ln t on.

3.3 EMud Agents

n n u g nt r th l m nt th t po k ll n th lon n tr n orm th orl ppl ng th k ll . u g nt houl on r o t r g nt 20 . S n th u llo n ontrol m h n m to u

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BEGIN LOCUS Library
SIZE 200
CONTENTS Table, Book1, Book2, Cat, You
EXITS Hallway, Livingroom
END LOCUS Library

BEGIN ELEMENT Cat
SIZE 8
SKILLS look, move, purr, eat
CONTROL CatBehavior
END ELEMENT Cat

BEGIN CONTAINER You
SIZE 15
WHEIGHT ALLOWANCE 15
SKILLS look, move, get, drop, open, close
CONTENTS Book3, Glasses
CONTROL ByTelnet
END CONTAINER You
```

Fig. 1. t p l u n t lz t on l

or n g nt r nt l l o utonom n h . hr un m nt l l l n t ngu h 26 . rom utom t g nt utom t t mpl ng th t th g nt h to t n ronm nt n n nflu n t o n utur x t n through t on n th t n ronm nt (pr r qu t or n g nt to utonomou 22) on to op r t on ll n h or ll utonomou g nt . Op r t on l utonom n th l t or th g nt to op r t thout hum n nt r nt on n h or l utonom uppo th g nt p l o tr n orm ng t pr n pl o op r t on. Su h n g nt mu t l to xpr r n h or t n or n ronm nt h ng . h mo l o n utonomou g nt r gur 2. n th pr l m n r tok n group ng xp r m nt pr nt lo r l ng th op r t on ll utonomou g nt ut p rt rom llo ng hum n ontroll g nt to nt r n u n urth r xp r m nt ll m nl on rn th u l ng h or ll utonomou g nt .

3.4 The EMud in Operation

rom th t rm nolog n rpt on t l r th t t th nt r o th p pl t on l oor n t ng nt t th t mu t h n l th nt r t on t n l m nt po ng k ll n th orl . n t u to th p r t on o th on m k ng lgor thm n th n ronm nt th t h n l h ul r h h n th l t o l m nt qu nt ll r qu t ng omm n rom h

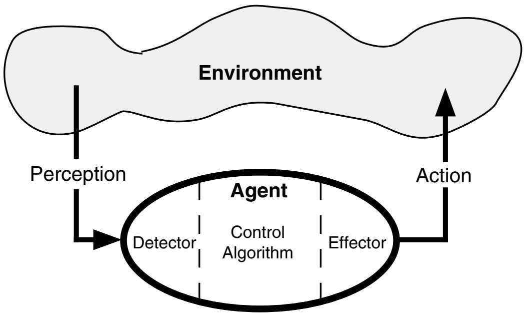

Fig. 2. n g nt r h t tur

o th r ontrol m h n m . h omm n th n nt rpr t t th l l o h l m nt k ll n ppl po l . h orl t l n p n nt o th t p o ontrol t m t hum n ng or n lgor thm o om k n th r mpl l nk t n n l m nt n t ontrol un t on n th ontrol t m n n on th gur 3.

3.5 Implementation Objectives

Wh n mpl m nt ng th ppl t on h h l t o m n go l n m n ; r t to m nt n th n p n n t n th rtu l n ronm nt k rn l n th ontrol lgor thm or n u l or popul t on on to k p l rg p rt o xt n l t to th ppl t on n o r ll g m or nt purpo . h r fl t our nt r t o ng l to tu r nt ontrol lgor thm th n th m n ronm nt n l o n on ph to l to ttr t th l rg num r o t t t r l l rom th nt rn t h n t rt tu ng th t o hum n nt r t on th omput r pt l t (not th t th t r on o th u l t ln t to u p .un r. h on port 4000 h n not un r r on n m l to h tr). h t o t p r p rt o tr n t on rom th tu o pt t on th n pur l rtu l n m l orl to orl h r om r l orl p r m t r h to t k n nto ount th ontrol t m .

4 EMuds as Experiment Environments

u n tur ll pro n ronm nt or th l l n m t xp r m nt u h th rt l nt pro l m 4 or W l on oo xp r m nt 2 ut u to th r hn o un t on l t l l or th r pt on o rtu l orl n g nt t on th r n th r mor u t to ppro h mult g nt t m on omp r t l l. S n g nt r mpl m nt plug n nt t r n n p n nt ontrol lgor thm t po l to rr out omp r t

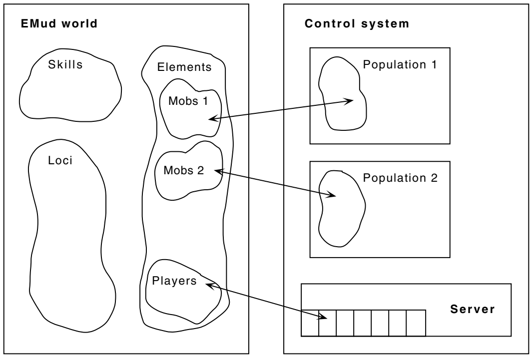

Fig. 3. u tru tur “ rtu l orl n ontrol orl ”

xp r m nt th nt r t ng g nt ho ontrol lgor thm r o r ll r nt n tur . Wh n u th popul t on o g nt th po l t op n n p r p t or th tu o oop r t on n omp t t on.

W urth r nt to l to on ront rt l g nt n th r n ronm nt th r l orl nflu n n th n on u ng th g m l k n tur o th u to u l rtu l orl r h nough to ttr t hum n pl r rom th nt rn t. h rupt on o r gul r p tt rn th n n n ronm nt h n hum n nt r t on pp r houl g n t on o th ro u tn o th ontrol lgor thm u .

4.1 Preliminary Experiment

n ntro u tor xp r m nt u to t t th u ppl t on h m pl m nt r group ng g nt orl n 6 . n th xp r m nt op r t on ll utonomou g nt r tu t th n t o m n on l toro l gr ont n ng tok n . h n mo n th our r n l r t on p k ng up or ropp ng tok n long th . rom r mpl t o rul r group ng or p r ng tur n o r to m rg n th n ronm nt. h ontrol lgor thm o th g nt ork ollo

) h n n g nt nt r mpt ll noth ng h pp n n th g nt mo on;
) h n n g nt nt r non mpt ll h l rr ng tok n t rop th tok n n mo on;
) h n n g nt nt r non mpt ll n o not h tok n t ppl pro l t rul to h th r t ll p k up tok n or not or mo ng on.

h pro l t rul u n th on to p k up tok n P(p k up) $N^{-\alpha}$ h r N th num r o tok n lr n th ll n $0 \leq \alpha < 1$ r l lu . W ho α 0.3 t xp r m nt ll n to g goo r ult . n

th xp r m nt n g nt n rr t mo t on tok n t n g n t m . Wh n mo ng th g nt r n oml l t on o th our l l r t on th n qu l h n to go n h r t on. h onl n or n orm t on l l to th g nt h r th num r o tok n n th ll h t n ng n n th pr n or not o tok n n h o n n ntor . On n th p up r ult o th xp r m nt u ng on to ourt n g nt n th orl on gur 4). h r ult r g n r t u ng gr ont n ng t n tok n . or

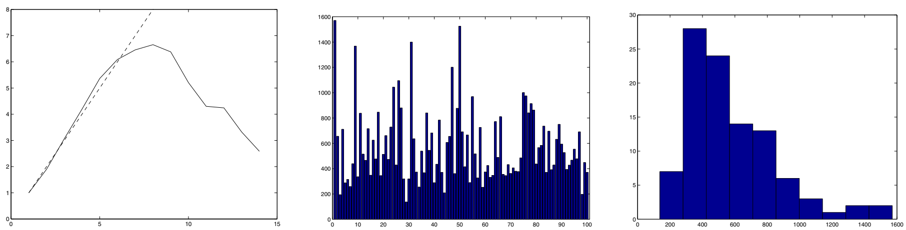

Fig. 4.) p up num r o g nt)) t p l xp r m nt (g nt)

h num r o g nt hun r xp r m nt r run u ng r nt n t l on gur t on th r ult ho n ng n r g o r th hun r . on n th pro l m n ol th l n r to up r l n r p up u ng t o to x g nt . rom th n on mor g nt t n to o r ro th n ronm nt rupt ng th r group ng p tt rn xh t h n r g nt r n ol . o umm r z oop r t on m rg n th mult g nt t m h n th num r o g nt r ng rom t o to ght. On gur 4) n) pl th o r ll r ult o hun r xp r m nt u ng g nt . gur 4) plot th num r o t r t on n to h th t k n h xp r m nt. gur 4) ho th tr ut on o xp r m nt r u th num r o t r t on . h r g num r o t p u 4 th m x mum n m n mum ng 1 1 n 13 r p t l un rl n ng th t th t u o th utonom o th g nt n though kno th go l ll r h nnot kno ho or h n.

h or g n o th r group ng pro l m l n th tu o oop r t on th n mo l ro ot g nt h r th un t on ng o hol group p n on th n u l omp t n o h ro ot ll th r nt r t on . m rg nt prop rt o u h t m r n l z n 6 n o port ng th m h or to th h p r mo l ro ot 1 . h nt g o u h n ppro h n oll t ro ot th t t l m n t th n or glo l po t on ng t m or o up r or mon tor ng th t k o tok n . h lo t on o th t k ont n ng ll th tok n r ult o th g nt nt r t on .

4.2 Further Experiments

W r urr ntl mpl m nt ng mor ompl t n ronm nt h r t o t p o h or ll utonomou g nt o x t h ng r nt k ll . n th x p r m nt g nt h un up r l rn ng p l t n r r r or oll t ng tok n . On t p o g nt llo to p kup tok n h l th oth r n onl t l th m rom g nt lr rr ng om . rom th tup xp t to o r ggr h or m rg ng n th th ng g nt h l th norm l oll t ng g nt ll mo t l k l lop p k up n run tr t g . h ontrol lgor thm or th g nt ll m o l rn ng l r t m (S) 10 24 g ng th m oth m ol on t on t on rul m h n m n l rn ng through r n or m nt n rul r t on. h nt r t on o t o l rn ng l r t m ll g n t on o ho rul ol h n on ront th n m l n ronm nt.

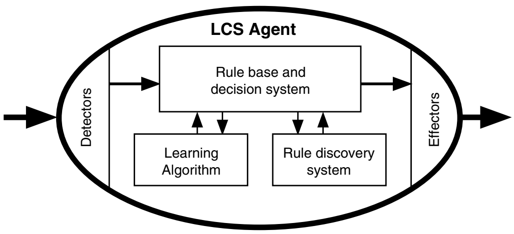

Fig. 5. th S mo l o n g nt

r n gur th S g nt r h t tur on t n rul r n or m nt l rn ng lgor thm n rul o r t m. n ronm nt m g r h th t tor o th g nt n r on to th rul h r on t on m t h ng p r orm o r th t o l r n th rul . t h l r th n or th r ppl t on p rt p t ng n n u t on th nn r g n ng th r ght to ppl t t on p rt. on qu n o t on r ont nu ll lu t th r n or m nt l rn ng lgor thm h h r r or pun h th l r or l r r pon l or th l t t on. h r r tr ngth n (r p. k n) th l r or th n xt t m th t k p rt n n u t on. t r pr t rm n num r o t m t p th rul o r t m g n r t n rul rom th tt t ol rul n r pl un t on n th rul .

5 Conclusion

h nno t p t o th ork to r on l m ol ppro h th n nt gr t ng h r t r t o oth top o n n ottom up t m nto ngl t m n m l n u to omp n t or th kn o h

t m. On th on h n top o n t m r non m o t m ho un t on ng on m ol m n pul t on. On th oth r h n ottom up t m r m o t m ho un t on ng on m rg n . u n orpor t oth m o m nt n m ol m n pul t on tur . h nt g o th h r t m l n t prop n t to ol r on ng g nt n n th l t o th nt rn l tru tur o th g nt to th gn r.

W h t k n th th t ph l groun ng not n r on t on or n t m to groun r th r th t m ol groun ng oul r l r t t p long th to u l ng ull groun t m . n r th umpt on t m l to g ntr n m n ng to th m ol th m n pul t n th r o n m ol un r ll not r r rom g ng m n ng to o j t out th r orl (. n th ph l orl) n p r through n or . h g nt rtu l orl t ng lt r through h h th ph l orl r h m ol ll n mm tr to th t th h h hum n n r h nto th tr t orl through th r h gh l l ogn t un t on on ph l pro .

W h th n pro to u l th u ppl t on pro ng r h rtu l orl n ronm nt or rt l g nt to ol n. Our m n go l no to g n ull l xp r m nt t k ng nt g o th r t m ol to l m nt n th orl ll n lu ng hum n ontroll g nt h r ng th m n ronm nt. O nt r t oul l o to xt n th u orl po l t mpl m nt ng tr ut r on u ng oor n t on l ngu g u h S 1 o th u ppl t on llo ng g nt to mo t n omput r r fl t ng m ol olog l n h .

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Towards Virtual Experiment Laboratories: How Multi-Agent Simulations Can Cope with Multiple Scales of Analysis and Viewpoints

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Abstract. n u ying ompl x p nom n w ug i ul i o on iv un n no o y n l yn i p o w i om m ny in ing v n p o u n m ging ogniz l p i n n u u lly l m o opi v n . u opi l i u ll o p i ool mong w i v lopm n o mul i g n im ul ion p ov p omi ing pp o . ow v u n mul i g n imul ion p ovi no m n o m nipul ing yn mi lly g oup o n i i w i m g i n g nul i y l v l . To ou min giving ull n o mul i g n imul ion woul on i oug in m king u o u po n i l g oup y g n ing m n xi n o i own n p i viou u p ovi ing m n o pp n ing mi o m o link wi in imul ion . p n on p u l fl xion on u n o g niz ion in lig o ou own xp i n in v lopm n o p oj O om w i im imul ing uno n in l ion p o . li v v lopm n o ou m o in l o p y i l p o will p ovi n w i n ool u ul o m ny mul i g n i u n mo lling pu po o o giv p o on p o vi u l xp im n l o oi .

Keywords: mul i g n imul ion mul ipl l v l o ion n l m g n p nom n mi o m o link.
T i i uppo y g n om n p m n o ig u ion n n y O om.

1 Introduction

o x o o s s l o o l sys s o s l o o o l x o . o s o s s s o s o y o l s w y s. s l y o l o l s s l l o l s o o s l y y v o lys s y o s o q v l y o s o . o o l

J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 205–217, 1998.

s l s ly oo o o ow o l o l y s s s s
o l ss o ls. Mo ov l s s l o o w
o sys s w v so ll yo s o o l ss o ls
. . osys o ll s s' so s s M N (o o l l 199).

ow v s o ss ov s o l w s y o
l x s o s volv o w o
s s l s o s o s w o o l x o
o s. l s l o s v so ov s o
o s v *a posteriori* s s o s v o
k o s l o l l v w o s w s l o
o s w w ly o o o s ol s o
o v w o o o w w s o o l ow o o s o
o ss o y o s s l o v ls w ow
v o s s so so o s k w s s v
s . y o y o s o v w o v v l
oll v s o v ls v l w s ow x s o
o s v l y s o ll l y s s o s s s
s s s o o v ools o o s l o x
s. o o wo l v s o o o v l x
l o o s o (199 40 4) o (l l 1997).

oj s o (P 199 ol 199
v 1997) w y o l o o w ll o s
y olo s s k wo o s v l w s o w lls
s w zo s flow w s . y v
s o . o s ow l v l s o s o o o y
s v o l l ws volv o o s s l s.
ll v ls s l s o s l s o
l o o w lls s s s s l
x s o vol o o oll v v y o s w lls (
s w y s s s s l ys s s l o oll v v y o
z l s); s o v w s l s o o o
o v w o w ll o s w l s s
sy s s o s o l o s o ll w lls o ly volv
v .

y olo s 's o j o s y s s s o l s l o z
s w lo o l v ls s v ly l o o . ow
v s o o l x s v l l v ls s s l o sly
o s o o o l y o v o o o lo l
v l. so y olo s s wo l v ll v s l
os o o o ll w s ows ow o l x s o v
x o o o o l s j s s s l s
s o o v s o w lls.

s v o l q v l o s l s w w ll o
o ly o s v l *a posteriori* s l s l o s x l .
o v s ss y kl y v ll s s o

o llow y o o s y s s lv s.
o s l o s lo lly y lly y
o o s w s o so s lly s l o
v s o s o o o o l y.
s o o o s l s o k owl o
ys l l w l o flow vol o v s l
x s o v o o w s s o s l v l y
o o ol vol o o low l y s. o s k
w l fl x o s w o s s s k sys ’s
o z o o j o sys s l .
s ll s o s ss o w ov v w o so x l s o l
o s l o l s l o s w w ll s ow l y o
s q s o s. l o s x l s l ly o
oj w s o l fl x o o ow o o o s
l s l o . l o o s v s o o s
l o l s o s v s o o s s (v 1997).
s o o w y o s l o ollow o s o l s
o o s l o ol ss w o o o
s.

2 The Need for Multi-Scale Viewpoints in Simulations

s o l o o s o v l s s l o s
o l o . s o ll l o v lo
o o os s o . l o fl s s l
o l s o ls w fl l s l o lls o
o wo k o s o ks w s lv s j o s
s fl . o ls ov l v o o sol o
o N v ok s q o s o o v o o fl
s w y v o o o s. N o s s s l s
l w o s s ss (k 1990 o ol M ol s 1990).
s o s s y oss l o l o
x s s o ss v o s v o
o o o s s l q o s l s s’ o . v y
s o s low s l v l o l y w o s o o
w lys s l v l o s y x . s o s s
ss l o l o o s v ’s ol s l o s (l 199) o
l v s l o lys s (P 1990). l s l o s o ys
l o ss ss o os o o l v l o os o
o o s ss l o s l o o w w s o
o l. o so l v l o s w wo l l
ss o os o o os o l v l o s l s s ss
(M l o 1997) s l o o q k s.
l k s o o l s l o s s w ll.
M N (o o l l 199) o s s l o s v l o

v s o o wo k o s l s v sks
s s k o s o s o oo s y w o y o
so so o x s o x s k so l o s.
o s ss l o j s o s y o olo s s w v
ss s o o o o . ow v s o s o o x s
s l o o o s o v o o o x
s ov . olo s wo l l k o o l o o
s so l o s s’ s wo l o s o o ly s oll v
y o v ls s o w o s. s v ly
o l o w ol s’ s w s ow s s
o s so s l y y l s . s s o s
s s so l o o s’ s s y s
o o q l y. o o s o s l o w ll
o o v s olo s s o o o s o s o v w
o s l o sly l .

o w y k look MM oj s
(M l 1997) w s l o l o l
ll o l ys . s oj vol o o l ’s
k owl s s l y o o s s so s o
so . s oss l y o s k owl w l l l v ls
o l y v s o o ov l v l o
l .

s o oj w ll s ov o s
s w s o v y. o o s w lls l
v o o v s. s l o (s s 1 2
) s s s y s o l wo k w ll s
y v q w ll. s s l y o lly
o w lls. v y y l lls ov o o ll o s
ll o low s o s o oo o 2 lls.
s v l oss l lls o s o ly os . ll s o
s v s s ll ll s ov o s l o .
lls y k s s s 0 s 1 o s 2
o y ll w s y o lo ov o
ov ow o s o oo . lls s o y o s s o
s s o w y o o o s v o v
o s. s w s k o ol ov o lls
l y l w ll flows s lv s v o l s o o s
o o s w o v lls ov o lls o lls. s o s
v s l o s v o s w l o ow l
ssol o w s o o o ll s o o
s o v s o k o w lls v o y l s s.

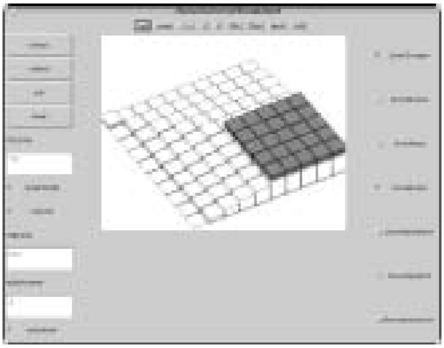

Fig. 1. l s . s s s o s ow k y. w lls s l

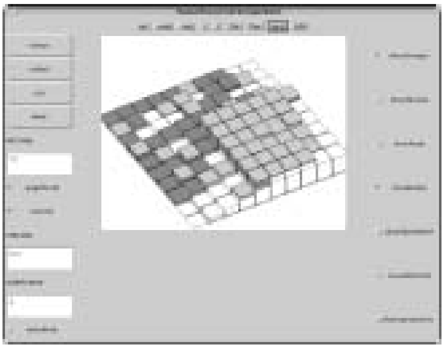

Fig. 2. o o .1 o v o sly oo x ssolv s s l s lls l y v o o o lls y o slo

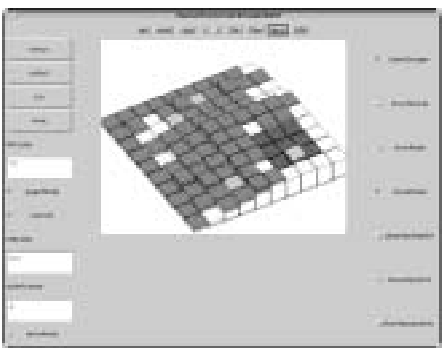

Fig. 3. l s . o s k y w o s o s. o o lls y o s o o v . w lls lso o l y

3 Regrouping Rules

o o s s s o o o so o
o o o l o w s s .4 w o s s s y
s s v ls o o s s y o lly v
o w wo l o o s o w lls
o s o l z y l o s o s o
o o l ; s o w lls k los s o
o w lls s o v . s l o o lls o o y
s o s o ollow o o s (ov o o l)
v o l o s s los o o o
v o oo (l l 1997). o ko
o o o s l y o .
l o o s s l o l k o oj
s o o y o s o s v s o o l s wo l
o o o o s o s. o o v s o s l s
o o s

1. l s w s s o s s v s o o
s l o ll y k s s 0 1 o
y w ll 2 ll o s s y o lo
l v ll. ll s 2 o s v s s o oo o
s s o w lls s s o s s o o .
l s o y v o o s w v o s
v l s ss o sk oo s k o
s .
2. o l o s o s s o lls o v o s x l
o s o s o l v s o l
o s o s lv s v o olo y. s o oo s
o ss ly s o lls y ly o o o s
w y o ll o s w y l y l sys
w s s s o s l w q o x o
wo l o s s o oo . yo w y lso
s l o s l k o w o s
. s o s look o o o o w (Mo k s
199) w o w s y s o s so l
o s ’s q s s o s lly
look o o o . w s wo y s o s x s l o s o
q s o o l ss o w s o s ss o
sso o l o w s o s ’s s s o .

o o w s y s o o o o s
l s w o s’ s s. lly s k s o
o o s o o w o o s o o j v s
s o o . os wo s Ea
Eb s v s v o s w o $\not{E}a - Eb \prec \theta$ w θ s s

v v o o s llow w wo s o s
s los o o .
v lly s y v o o l w so o o s
o o s s s o s volv o o
ow o l o o o v so s o l w s s.
o o s ly l k o o o o s. s s o
s l o o s o s l l s s o w lls.
o o ss y o s s so so o y lo l
o o o o s o s l y l l 1997 s
o o o o l o s w s o s lly o lly
o s o l z o o P ys s. o o o
o o o so l s l o s s o o o y
s s lv s o l v sys l v l o o l x y q
o s l so s “ s l o s y v ov s l o
s s o s lly so s s o s (s)
s so s l o so o so o ly o
o s o ow so s” (l 199).

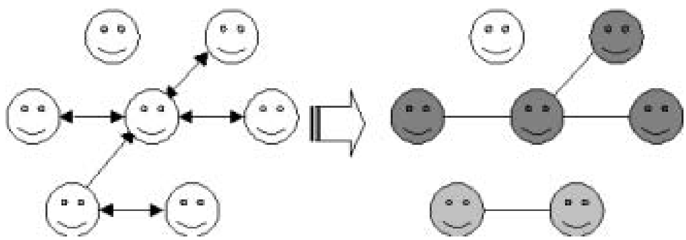

Fig. 4. o o v l s

4 Adhesion to a Group

s s o o o s s w ow v o k o
s s w l o o o s s l . lls v y o
l l s s o lls w s so o s s o
s s o v o . ow v ow o s s s
o v o s o o wo s ow o s l s v o
o ?
s o ll w w o l o w o o o
o y s. y lly s o l o q y
o o s o l ly l. ow v o x o o l o s o
o j v s v l s o o o so o o y o so o
y s. wo so s o o o o

1. o o o y s s w ll k ow o j s o
s y o y olo s s s w y o v o o y o s ly oj
s l o k owl s v o s o o
y s. s s l y ov w x o o y o s
o s l o y x s o y o o
y so s o o x s w ll o s v v o s o
y o o o v o sly s lly oo x s s ow .1.
s l o w ll o o v l x s o s o s.
y o s ly o o o w lls os s s s
v o o v o s y k ow lo l l v l flow
w o o k ow ow o l s o w lls wo l o
o . y o ly k ow o o vol ow y w lls
w ll o o v l os o s s s.

2. s s v w w o o v o o (o o o w o s os
o o) o o s w o v y o o o
o o o s w lls *water* o . s w ll
s x l o 's x s o y ll wo k w s s
(x l o 199) o s o l o o v w ll wo ks
s o v s o s s s (s s
s o olo s) o x l v w o w
o v w o ( ) w s o ly s o s ow (o
x l w o s s w s).
o v o o l w w o o s y o
s l o .

ll w y w o o o s o s w o
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o o s .

s v l s o s w os y s o
os y s o wo s y o l y o
o s. s o o o y o s s l o o ss
o s. y v so so o o s s s v
o o vo o o o o o . o s
l o 's s s lo s o o s s s y s
o v l s. o o oos s o w s o
o s o w o s. s v s o o
s l o w v o o o y l v l
wo l o . s v y o s s l o y l o o
v oos s o w s los o s l . l o o s
s s os sys w y k o w s
o sys s o vo so s o solv o l o fl s w
s v l oss l o s.

5 Control Issue Within the Group Agent

s s o o o o . s s lly o l
l v l v s ow o o y s s l v ls s o
l ws. s lls x lls o o w s v s ll
x s w wo o s v o l s. s v s o s w y
olo s 's w o so s s o flow s. Mo ov s s l o
o l v ls w s o s l y v s s s o s
o o z o o o so s s o l y o ll
o o o o s. o o l s s ll l o
w x s lw ys l low s l y l v l.
o s lo o l y l v ls v l o
l v l . x s w s o s l v l o y o l v l's
ow l s s o lls ov . ss o o l v l
o o o s w l o s o s l v l. o s
ov w s l s l y
l o o l ssol o w o s o y s low
l v l s lo o . v l s lo o o s
v v o l s w y s sol oo
s o s ly j s s w lk w s o o s. s ll w
lo s o v k s o v w lls o s o lls
o lo s y s (o o). s lls s s o k
o o v w o ow o ly l s flows o
o s o o s. lls o lo s o o lls o lls w
v o v 's o o s flow .
v l s o o so so o o o l y w
o o lly olls o s l o o o sly.

6 Coexistence with Recursive Regroupings

s l o l o s o v s o o y o
l l l l v l o s s . . lly l s o
s l o lys s o o o s l o sly s s v l l v ls
o lys s. s s s o o y l o ll l v ls
ov y so w . y s o s k
o s l s o s s w s o k s s s v s
o s. v o s w o s. v l y s ok o
o o o s s o o o o o oo . s o l o
s o w y s o l s o l o s
so l o s . v o s y k ow o s s
w ks o o l s. s s o w s s flows v s
y o o o w o l wo k w o l l w
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ow v wo k s s s o s w
l y s w y s o o s o . os
s l w y o s y o s s o l z s o s o s o
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ll v ? s w ll o lw ys so y o ? ll s q s o s v o sw y s so o s s w v l o v s o s s o o s o l wo k o lls o w s sy o s w o o ll s w lso s o l s o o w s o o s.

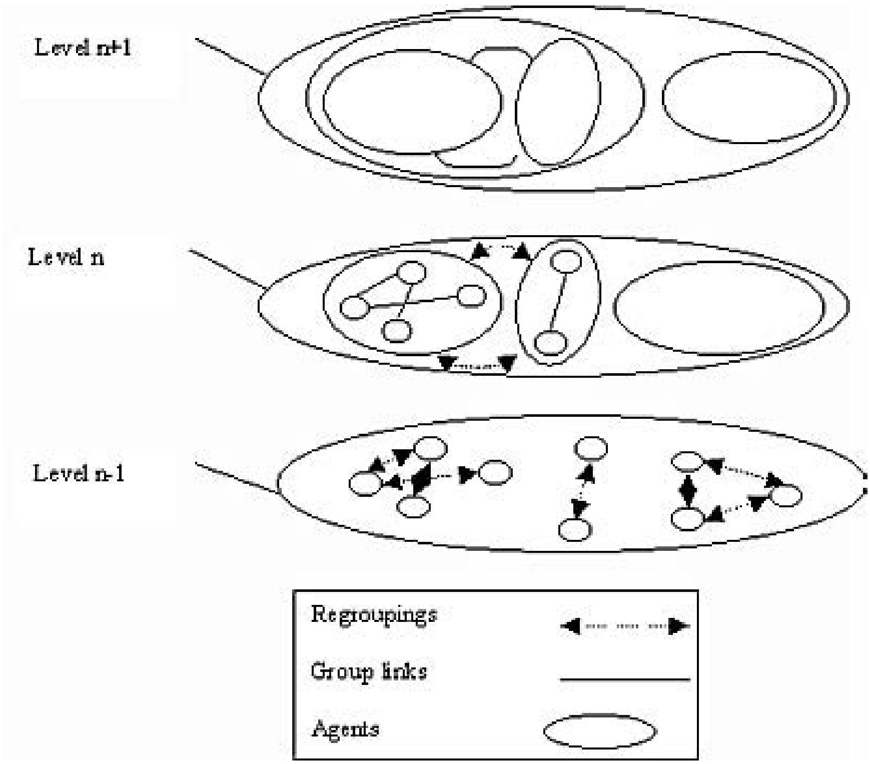

Fig. 5. o x s o s v l l v l o lys s s v o s

7 Conclusion

v s s o o fl x o o ow o o k o o x s o s o s w l s. v s o s s o o o s o l o l s o s l s o o o s w l s o l w s l o s o l y w s o l o y olo s 's.

ow v l o o x o s o o j v s l s y s s s s o o o l w o o o o o l z s o s l s s o wo o

v y o o o w w o s l . v o y y
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k owl s o o w s o q s s s s y
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s s s l o o o o o o ss o
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s s ow so k o y w s o o j v s o
l o s s lso o sy o z o o o o o
l s o v ls s lv s s w y s ow o
o s . s w o yo sol o j
o ll ss s. o j o sys s o s
o z o lly s s y o .
l sys s ow v o z o v o s
s lv s o j s w sys lly o o v
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l o s oj s o l y l s s
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y s o v s o o s s o o s o l
sys s w o v s o ls o s v s o . ow v
s s o v so l o ow w y o s l o j s
v o o o s o o s w z s o sy o s .
ly o j v o o o s w o
s s l s w ll v o ov o w
s o s l . s’ s w ll o o ly s y
w s ow s v o s l ss l o s
y w o s l o sol s o o s s s
ow s o v l x s o o s l o
oll v v y o o o x s w . s o o y

s s ov s w y o o j o o s v o l.

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A Model for the Evolution of Environments

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Abstract. In artificial world research, the environments as themselves are rarely studied. Both in multi – agents systems and artificial life domains, the dominant work turns around the active entities, the agents. The aim of this paper is to propose a theoretical approach of an environment model. It must allow to deal with the different existing environment types but also to add a creative touch by introducing the concepts of meta – environment and multi – environments. This model defines some evolutionary schemes for an environment, and the different ways of interaction between them.

Keywords: adaptive environments, environment model, environment interactions, multi – environments systems.

Introduction

John Holland quotes in one of its first papers, [1], « The study of adaptation involves the study of both the adaptive systems and its environment. In general terms, it is a study of how systems can generate procedures enabling them to adjust efficiently to their environments ». However, since 1962, most of the research work are focused mainly on the adaptive systems, rather than on their environment. This paper is a first step into the task of filling this gap, and proposes a theoretical study of an environment model.

Even if most of the works on adaptive systems integrate the idea of a dynamic environment, generally, it only has a weak level of dynamism and it doesn't really have a truly evolutionary process. That is why it seams important to consider the

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environment not as a dynamic support where agents populations, [2], or animats, [3], evolve, but as an entity by itself. This entity will be able to develop particular behavior models, but also a non – fixed structure. These environment behaviors should be able to evolve following the different interactions with its objects and agents.

Nowadays, most of the systems include an environment containing agents and objects. But, couldn't a system integrate more than one environment ? In such a case, it is necessary to define, from on side, the different interaction laws that can exist between the environments and, from the other, a meta – environment being able to manage this laws considering each environment as an agent.

The purpose of this paper is then to define an environment model which integrates all of these ideas. This model must allow to classify and to order the environments, giving by this way the possibility to determine transition and evolution stages between the different environment classes.

The task of the first part is to establish this classification in a hierarchical way. Then, the second part presents the concept of meta – environment and the different interaction types that a multi – environments system can have. The next part concerns the definition of a protocol for the environments evolution and finally, the last part shows an example of a multi – environments system using the model previously defined in this paper.

1. Environment Model

This model lays, from one part, on the definition of a taxonomy of environment classes, and, from the other, on the use of the characteristics and parameters of each of these classes. From an object classes point of view, and also for simplicity of use, the chosen hierarchy is a simple one, i. e. each object have one and only one father.

Taking into account the important use of some artificial life techniques such as genetic algorithms, [4], and classifier systems, [5], a genotypic description of the model classes is presented to conclude this part

1.1. Taxonomy and Classes Characteristics

This taxonomy defines five main classes. Two of them are abstract ones and the other three are concrete ones. The Fig. 1 shows this hierarchy.

The *abstract environment* class is the root class of the hierarchy. It has some parameters, which are common for all its sub – classes :

– *The environment size*, denoted S. This parameter determines if the environment is infinite or finite, and in this last case, S contains a positive integer value, which the unit depends on the environment type.
– *The set of the environment objects*, O. This set can be decomposed in some parts : the active objects set, i.e. the agents, the inactive objects set and the sub – environments.

– *The set of interaction laws* between the different environment elements, I. This laws concern the interactions between agents and objects, agents and agents, but also the interactions between the environment and its components.

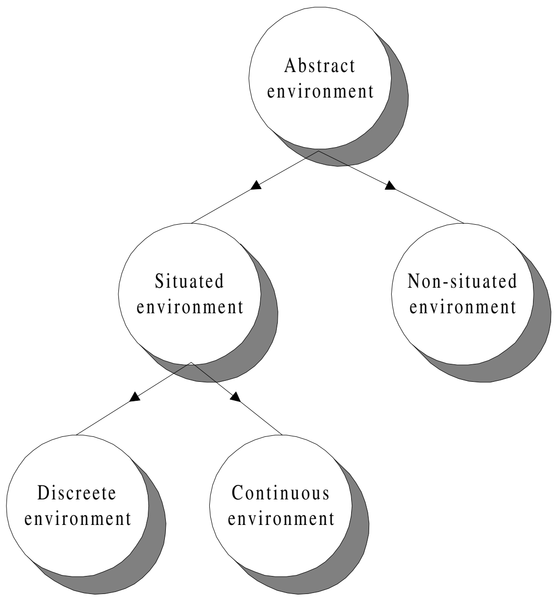

Fig. 1. : Environments taxonomy.

– *The set of evolution laws* of the environment, E. This set determines the rules followed by the environment to evolve in time, and also the transition functions which allow it to pass from one stage to another.

The quadruplet <S, O, I, E> defines then an abstract environment.

The *situated environment* class is generally used in the simulations concerning the multi – agents systems, and the different problems in artificial life. An environment is called *situated* if it is constructed from a space having a metric, and if its objects and agents have a position in relation to this space. The parameters of this environment type are :

– *The structure or architecture* of the environment, A. Different structure types exist, as a toroidal space, square, cylindrical or spherical.
– *The environment dimension*, D. The environment can have one, two, three or n dimensions.
– *The environment metric*, M. This metric defines the measure units and the scale to define the objects coordinates within.
– *The set of the space management properties*, P. This set is formed by some properties as the projection properties, from a dimension n to a dimension n-1, for

example, or even more, the rotation properties, useful for the visualization processes.

In this kind of environment, the agents may have some particular properties, related to their situated aspect, their coordinates, their movement coefficient - or their speed - representing their capacity to move.

A situated environment is then defined by the set <S,O,I,E,A,D,M,P>.

The *non – situated environment*, N, is the class that can be used to define an environment in a ruled – based system. An environment is called *non – situated* if the concepts of space and position into space don't exist in it. In this kind of environment, rules can be considered as the objects and meta – rules can be the agents. This class doesn't have any specific parameter, due to the fact that it is defined to be distinguished from the situated environment class.

The *discreet environment*, D, follows the principle enounced by Bergson, [6] : « The intelligence only represents clearly to itself the discontinues ». An environment is called *discreet* if is it cut up in a finite number of elementary parts, the cells, each one having a fixed number of neighbors. The parameters of this type of environment are :

- *The cells structure*, L. These may have different forms : square, hexagon, or triangle in a two – dimensional environment.
- *The integer environment metric*, Mi. The environment being cut up in elementary parts, the computation of coordinates and moves are done in the integer set, or in one of its sub – sets.

The *continuous environment* class, C, is the complementary class to class D. An environment is called *continuous* if, for every two points of it, there is at least one point between them. Even if, from a computing point of view, the idea of a strict continuity is impossible nowadays, a continuous environment can be built using a *real metric*, Mr, based on a real vectorial system. This kind of metric is the only parameter of this class.

1.2. Genotypic Approach

All the previous parameters can be coded to form a string, genome or chromosome. The elements of this genome, the genes, define then the different environment properties. Once this coding has been done, it is possible to apply a particular version of Genetic Algorithm (GA), used in artificial life area.

This kind of algorithm would be near to the BEA, Bacterial Evolution Algorithm, presented by Chisato Numaoka in [7]. In opposition to most of GAs, having a large number of strings, this one considers entities, the bacteroids, owning only one chromosome. The bacteroids behavior is then completely determined from this unique chromosome. The evolution phenomena is performed just when the bacteroid, weaken[1], inserts in its organism the chromosomes of its neighbors. It chooses a chromosome in this set and, eventually, makes a mutation on this new chromosome.

In the same way, environments following this approach have only one active string. This chromosome, which determines alone the environment *genotype*, defines

[1] The bacteroid have an energy level.

the environment itself, its *phenotypic* representation, and its behavior. The chromosome fitness is then defined according to some parameters like :
- The number of objects and agents in the environment.
- The agents efficiency, which can also be measured as a fitness.
- The utility of the environment laws.

However, as a difference with the bacteroid case, the environment keeps the old chromosomes in a kind of memory base. This memory is then used in the evolution process to eventually return to an older, but more adapted, state.

After the description of an isolated environment, a description of the possible relationships between different environments is presented in the next part.

2. Meta – Environment Notion

When the different elements of a system doesn't act and interact with the same time scales, it can be useful to decompose it in a set of sub – systems. Effectively, it is not always coherent to consider in the same way the events produced in a micro – second scale and others produced in a year scale. The temporal windows of the evolution are completely different and cannot be managed with the same rules.

At the environment level, this decomposition leads to the constitution of a multi – environments system. However, to take into account the different interactions that can be performed between the environments, it is necessary to establish the concept of meta – environment. This one doesn't act as a supervisor but as a service manager, giving its services to its sub – environments, avoiding them some tasks. And even more, this approach allows a modular development, creating a hierarchy of environments and sub – environments, managed by a unique meta – environment.

2.1. Characteristics

A meta – environment is a kind of specialized abstract environment, having the following properties :
- An infinite size.
- A set of objects, exclusively environments.
- A set of laws for the interaction between its sub – environments.
- A set of internal evolution rules.

2.2. Global and Local Meta – Environments

It is important to point out the fact that a parallel can be established between the environment / agent relation and the meta – environment / environment relation. In the second case, the environment acts as an agent in relation to its meta – environment.

Following this idea, an environment can contain other environments as components. In this case, the environment containing some sub – environments can

be considered also as a meta – environment. So, two types of meta – environment exist in this model :

– Global meta – environment : the root of the multi – environments system hierarchy. Its properties are those defined in the previous section.
– Local meta – environment : a node in the multi – environments system hierarchy. It is a component of another meta – environment, a global or a local one. It contains as a part of its objects set, a set of sub-environments, which can be considered as agents in relation to it.

2.3. Inter – Environments Interactions Types

A large number of interactions between environments can appear. This section describes some possible ones:

– *Environment dependence*. An environment is completely dependant from another and can only perform its own actions according to its master environment.
– *Transfer*. An environment can transfer either agents, or objects, or laws to another environment.
– *Communication*. An environment can establish a communication with another environment in order to ask for, or to offer, either some information or a transfer.
– *Union*. Two environments, both having almost identical elements, can join in order to form an unique environment, composed by the set of all the elements of both original environments[2].

The environment evolution can be caused, as in the next example, by its components, but also as a consequence of the evolution process of the other environments in its system. In this case, the environment evolution will be caused by a state change, controlled by its transition functions. Its corresponding meta – environment will detect this change and will inform the other environments. For example, if some environments share some resources, and one of them disappears, the meta – environment will transmit this information to the others to allow them to adapt to the new existing conditions.

The next part describes an example of an environment evolution caused by its agents.

3. Environment Evolution

In the evolution process, an environment can have different states. An environment has an *initial state* just after its creation, a set of *transitory states* during its life period and a *final state*, the one before its death. All this states are linked together by transition functions. This environment evolution concept is important for the meta – environment, who needs to know the situation of its sub – environments in order to make the necessary changes for all of them, but also to create a new one or to destroy an existing one.

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[2] An environment could also have the possibility to be cut, to give two distinct environments.

3.1. Evolution Types

In the frame of the situated environments, these can be confronted to different kinds of evolution. This section presents the laws that allow them to evolve in different ways :

- *Structural evolution*, the environment deeply modifies its structure. For example, lets have E, a discreet situated environment. If E is a two dimensions environment, defined by a 15*15 grid then, after a structural evolution, E could increase the grid size to 16*16, or decrease it to 14*14. This type of evolution can also occur on the dimension parameter, so a two dimensions one can evolve to a three dimensions one.
- *Behavioral evolution*, the environment internal laws are modified. Considering the previous example environment, E, if it has some resources as a part of its objects set, an internal law can allow it to control the quantity of renewed resources at each step. A behavioral mutation will change this kind of criteria, increasing or decreasing it, in order to encourage or not the expansion of the agents feeding with this resource.
- *Component evolution*, the environment acquires or destroys types of objects that may compose it. In this way, the environment E, evolving by this principle, could define a new kind of resource, more appropriated to one type of agents.
- *Geographic evolution*, the environment creates or destroys some instances of its composing objects. In the environment E, after a geographic evolution, E would be able to create, on some cells[3], new objects, new resources or new obstacles. This evolution type, where instances of objects are created or destroyed, must be distinguished from the previous one, where types of objects are created or destroyed.

3.2. Evolution Example

This evolution example uses a two layers neurons network to determine the mutation of the environment genome. This kind of evolution fits to the interaction between the environment and its agents. Then, some specials environment interaction effectors, represented in the network by input neurons, are affected to each agent. At each gene of the environment genome fits also threshold functions, causing a gene mutation after their overall activation. These threshold functions are defined by the output neurons of the network. As shown in Fig. 2, each output neuron is connected to each input neuron.

When some agents activate the same environment interaction effector, the signals are transmitted to the corresponding output neuron. After that, if the function threshold is reached, a mutation of the corresponding gene will occur. This mutation may be interpreted as a demand of an environment modification from its agents. If a sufficient quantity of agents makes the demand, then, as a answer, the environment will adapt and transform itself, following the agents exigency.

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[3] If the environment is discreete, or at a position in space if it is continuous.

It is necessary to make the right distinction of the output neurons, which represent the activate functions, and the genes of the environment genome. In the following example, the environment E is a discreet one, defined by a 10*10 cells grid. Then, a gene codes the environment size, however, two outputs neurons will be associated to this gene. The first one represents an increase of the environment size, if it is activated, while the second one represents a decrease of this value. Then, if a sufficiently important agents group demands to the environment, by the means of the neurons network, to increase its size, it could be able to undergo a mutation of its corresponding size gene. The environment will mutate then to a size of 11*11 cells.

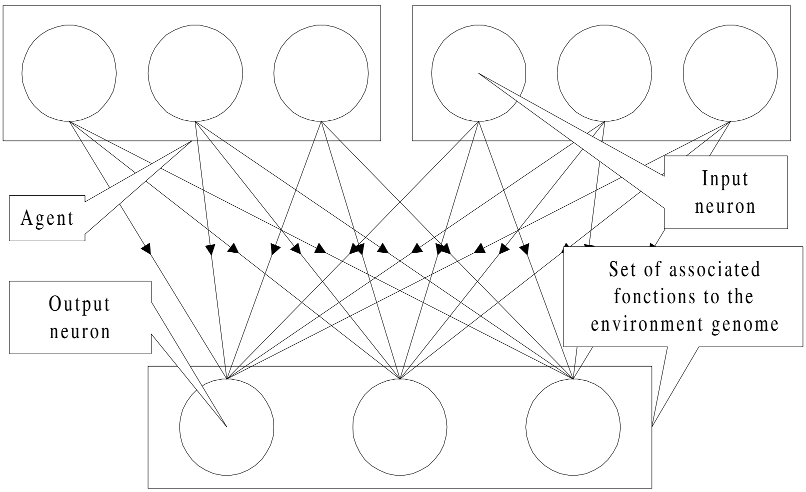

Fig. 2. : Two – layers neurons network.

4. Multi – Environments System Example

In [8], Nils Ferrand quotes some possible characteristics of a multi – agents system, applied to spatial planning : «

- Multiple scales : in space (from close neighborhood, to the nation or even continent), in time (from an instant for the perceived feelings of negotiators, to the centuries for the evolution of large scale ecosystems), and in organizations (from one – to – one interaction, to the transnational organizations) ;
- Multiple actors : except in some very local and specific situations (like a landowner planning some limited works on its own territory, with no visual or ecological impact), spatial planning implies many actors, with different interests, social and organizational position, spatial attachment, and personal qualities ;
- Multiple objectives : environmental, political, personal, economical, etc.

- Multiple modes : integrative (toward consensus through cooperation) or distributive (toward compromise through negotiation) ;
- Multiple criteria : ecology, economy, landscape, agriculture, laws and regulations, culture, society, ... »

The number of characteristics, non – exhaustive, denotes the difficulty of conceiving a complex multi – agents system using a unique environment and controlling a unique time unit. So, the necessity of building a multi – environments system appears, each of them having its own time and evolution criteria.

In a more precise example, which the aim is to simulate a ground area with its different components, the evolution time scales are very variable. If the simulation takes into account the underground level, the ground level and the atmosphere, it's clear that each of these elements and their internal elements doesn't evolve at the same speed. In this way, the life time of an ant is shorter than the anthill life time, which is shorter than the tree life time. However, the relationships between them are non – negligible and must lead to a co – evolution of each element. These distinctions induce then the creation of many environments having interactions properties to allow this co – evolution.

The Fig. 3 shows an environment taxonomy allowing to model the anthill evolution, according to some possible sub – environments.

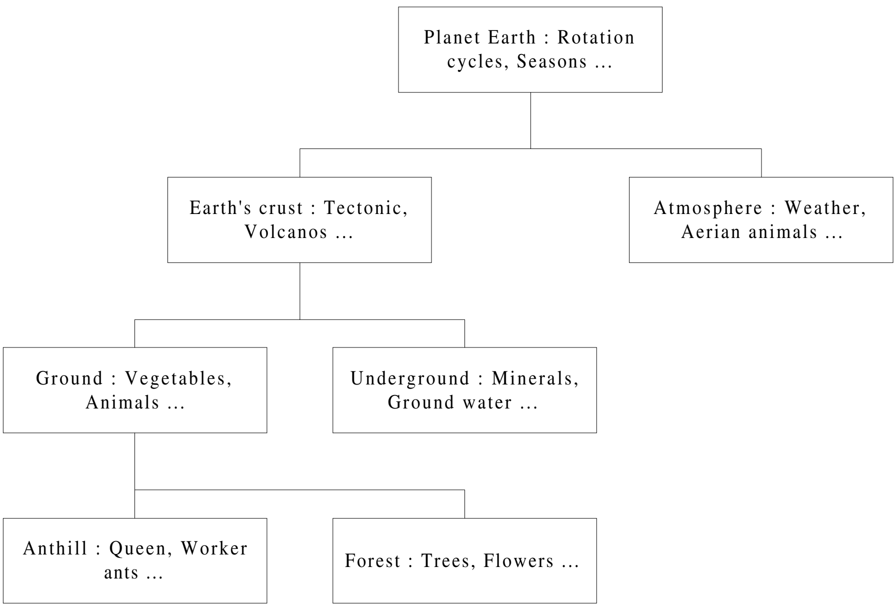

Fig. 3. : Example of multi – environments system.

Focusing only on the development of two sub – environments, one corresponding to the ground definition and its properties [9] and the other, modeling an anthill [10], the following characteristics are considered :

– Ground type (prairies, agricultural lands, forests, ...), water exchange (rain, evaporation, humidity level), carbon and nitrogen flow, temperature, plants decomposition (divided itself in some parts, following a chemical and physical protection index of the organic mater), plants production, ground textures (sand, clay, granite), ...
– Ants types (queens, workers, soldiers), cocoons and larvae with different states, ants cadavers, multiple ants nutrition forms, ...

Then, some interactions laws between these environments are indispensable to cause a co – evolution of the different components. This laws concerns :

– The substances transfers, an environment creates food for another environment agents, and these agents produce some rejects that allows the evolution of the first one.
– The geographic aspect, the anthill being an environment geographically placed at the ground level, as shown in the Fig. 3.

According to this decomposition principles it is possible to integrate, in a modular and progressive way, the other environment types to a developed system.

Conclusions

As it is shown in the example described in section 4, this environment model allows, from a practical point of view, to develop progressively a complex multi – agents system, defining and conceiving the sub – environments one by one. This model proposes different kinds of evolution for an environment. In this way, the agents evolution and the environment evolution leads to a co – evolving system.

In order to simulate artificial ecologies, the environment model described in this paper, can be combined to a food – web model, like this presented by Lindgren and Nordahl in [11]. These authors show different existing food links between many types of animals and vegetables, but they also put forward some special links : « Not only do plants and trees provide food for the herbivore, they also provide shelter from sun and wind, escape routes and places to hide from predators, and branches and twigs to make nests and squats from ». These types of interactions prove the difficulty to conceive a realistic model of a natural ecosystem, but the concepts brought in this paper should help to develop modular platforms.

Practically, the *componential model*, developed by Marc Lhuillier in [12], combined to this environment model would offer the possibility to construct multi – agents generic platforms. Those will tie together the notions of flexibility and dynamism of the componential model to the environmental evolution idea, described in this paper. In the future, a first platform of this kind will be developed, integrating the concepts of environmental evolution and meta – environment. Agents of this platform will be built with the macro – mutation concept, described in [13], allowing

an agent to undergo a deep modification of its genotypic structure, according to environmental conditions.

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ARéVi: A Virtual Reality Multiagent Platform

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Abstract. *ARéVi* (in French, **A**telier de **Ré**alité **Vi**rtuelle) is a distributed virtual reality toolkit. Its kernel (a group of C++ classes) makes it possible to create cooperative and distributed virtual reality applications by minimizing the programming effort. *ARéVi* is built around a dynamic multiagent language: *oRis*. At any time, this language allows to stop the ongoing session, to add new entities (known or not when starting the session), to modify an entity or an entire entity family behavior. More generally, *oRis* gives the user the ability to interact with the agents by directly using their language, thus offering a way of immersion through the language.

Keywords: Virtual Reality, Software platform, 3D simulation, Multiagent Systems, Dynamic Languages

1 Introduction

ur study is rt of r s r h works in virtu l r lity nd distri ut d simul tion toolkits (R oolkit 12 R- K 9 6 NPSN / S 5 15 nd 3 nim tion nd int r tion (23 - 11 irtu l Studio 1

n th l st f w y rs ig ffort h s n m d y uild rs nd d sign rs to im rov th r nd ring lgorithms nd to l or t i nt gr hi ngin s rious omm r i l rodu ts r now v il l orld oolkit (S ns 8 1991 d S (ivision or lovis (L 1995 r now lso witn ssing th m rg n of d s ri tion st nd rd of virtu l r lity li tions R L 2 0 S / 14772 14 v n though th h vior l or distri ut d s ts r not r lly t k n into ount y t n th ommuni tion rt th n xt v rsion of th P roto ol (P v6 R 1883 (m r 1995 introdu s th notion of flow nd in lud s th multi st his s t is ss nti l in distri ut d virtu l r lity

h r for ro os l for n w toolkit r hit tur for virtu l r lity h s to wid ly o n d nd m d s mu h ind nd nt s ossi l from th r nd ring li r ri s it must l to us th most o tim l solutions 19 20 t should lso l to d s ri l rg r nd l rg r nvironm nts in luding g nts with mor nd mor om l x h vior

R i is l tform for th d v lo m nt of istri ut d irtu l R lity - li tions t is writt n in ++ nd its k rn l is ind nd nt from 3 li r ri s

J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 229–240, 1998.

t m y us d for th r id d v lo m nt (s ri t rogr mming of li tions using “r l tim ” 3 visu liz tion with or without th imm rsion of hum n o - r tors h s li tions m y distri ut d for oo r tiv work h y n int gr t univ rs s inh it d y g nts whos h vior is mor or l ss om l x n this rti l w will m inly d t il th h vior s ts of our l tform f- t r indi ting th rti ul r onstr ints of virtu l r lity w will r s nt *ARéVi* in d t il its softw r r hit tur s w ll s th *oRis* multi g nt l ngu g th h rt of th syst m h n w will r s nt n x m l d s ri ing th syst m’s ossi iliti s in lly w will on lud on this l tform volution ros ts

2 Virtual Reality System Needs

h o j tiv of distri ut d virtu l r lity li tion is to llow grou of dist nt o l to work tog th r on ommon roj t (for x m l int r tiv rototy ing n ord r to l t th us rs on ntr t on th ro l m th y r trying to solv th syst m th y r using h s to s fl xi l s ossi l s rs don’t h v to d t to th tool th tool must l to t v rything th y n d to do

2.1 Modularity

h int r tiv rototy ing notion involv s t l st th o ortunity to dd r mov or modify l m nts in th syst m hus if w w nt th syst m to t su st nti l h ng s in its stru tur it must h v rt in mount of fl xi ility h multi g nt ro h s ms to th most ro ri t to rry out this go l h syst m d sign r’s tt ntion is fo us d on th individu l fun tioning of h of its om on nts h s om on nts h v to l to dis rn nd t on th ir nvironm nt (syst m’s oth r om on nts f w h v w y to d s ri om on nt int rn l fun tioning s w ll s its int r tions with its nvironm nt this om on nt will l to t k rt in th g n r l working of syst m m d of l m nts r liz d on th s m w y h r won’t ny glo l ontroll r nd th syst m will v ry modul r h g n r l fun tioning will th r sult of om in d tions from h of th om on nts nd will h ng ording to th us r’s int rv ntion on h of th m

2.2 Immersion Through the Language

h m in diff r n tw n simul tion nd virtu l r lity is th t v rything nnot l nn d wh n l un hing s ssion n f t rson initi ting virtu l world h s r viously l nn d to fill it u with v rious t gori s of ntiti s s w ll s th ossi l int r tions with th m h n onn ting us r h s to dis rn it ut do s not h v to limit d to this h s to giv n th o ortunity to ring into th syst m his own ntiti s v n if th y w r unknown to th d sign r his ntity su ly h s to don without int rru ting th syst m nd r onfiguring v rything n th s m w y to r liz his work

us r m y n d to int r t in th univ rs diff r ntly from th d sign r's l n must h v s mu h fr dom of tion nd int r tion s ossi l h t v r virtu l g nt is l to do hum n o r tor h s to l to do it too in ord r to on th s m l v l nd to h v th s m fr dom h o r tor h s to s k th g nt's l ngu g in this s w n t lk of imm rsion through th m ns of th l ngu g t follows th t this l ngu g h s to dyn mi it h s to t r qu sts nd modifi tions wh n x uting

2.3 Generics

h li tions of virtu l r lity r num rous nd involv tivity fi lds v ry f r from h oth r (for x m l t hni l uilding rgonomi s ins t o ul -tion study rowd mov m nts n vig tion in r onstru t d r h ologi l sit om ut r- id d surg ry t t is im ort nt for th on rn d syst m not to int gr t r str ints on th ty of univ rs it n r r s nt

o sum u int gr ting g n ri nd dyn mi multi g nt l ngu g in virtu l r lity l tform llows to o t in tool whi h giv s th us rs fr dom on rning th kind of ntiti s th y wish to im l m nt nd on th int r tions th y wish to r liz

3 ARéVi

n this s tion w r s nt th *ARéVi* (in r n h **A**t li r d **Ré** lit **Vi**rtu ll l tform his l tform is th r sult of our r s r h work

3.1 General Presentation

ARéVi li s in th *entity* *scene* nd *viewer* on ts h ntiti s r lo t d g nts with 3 r r s nt tion his r r s nt tion in lud s nim tions (su -ssion of s v r l r r s nt tions s w ll s l v ls of d t ils (r du tion of th f t num r ording to th dist n from th m r h ntiti s m y d riv d (in th s ns of o j t ori nt d rogr mming into m r s lights or wh t v r th us r wish s to

o r du th dis l y osts th ntiti s r rought tog th r in s n s wh n in rti ul r s n th only ntiti s to visu liz d r thos whi h r rt of it

h ntiti s in s n r d t t d y m r lo t d in it (ith r rovid d y th us r or d f ult r t d h im g s shot y this m r r s nt to vi w r (2 window to dis l y d

ll th s notions r illustr t d on ig 1

3.2 Software Architecture

h *ARéVi* k rn l is grou of ++ l ss s igur 2 r r s nts rt of th sso i t d mod l h whol fun tion liti s of th syst m x t for th

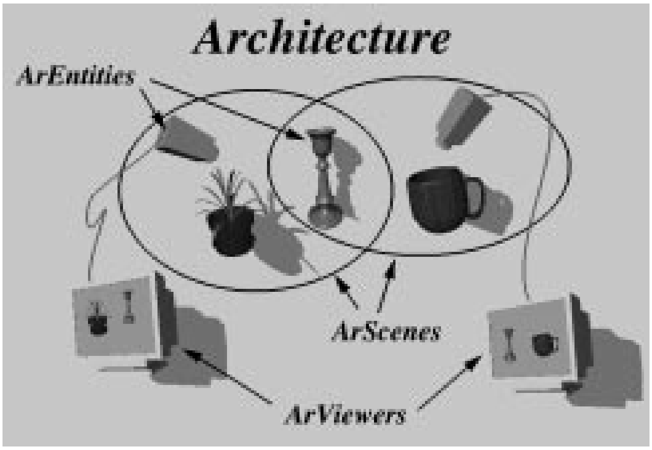

Fig. 1. *ARéVi* rin i l

dis l y r r liz d y l ss s (str t or not n rti ul r w h v l ss s for th ntity notion nd its d riv tiv s (`ArEntity` `ArLight` `ArCamera` s n (`ArScene` nd vi w r (`ArViewer` h ommon d riv tion from th `Agent` l ss is x l in d in S t 3 3

n `ArEntity` h s g om try (`ArGeometry` r s onsi l for m n ging its osition nd in m ti

h link with rti ul r r nd ring li r ry is r liz d y d riv tion of th orr s onding l ss s or x m l n `ArCamera` is d riv d into `ArXXCamera` wh r `XX` r r s nts on of th thr li r ri s lr dy su ort d n nv ntor (S ision (log nd n L

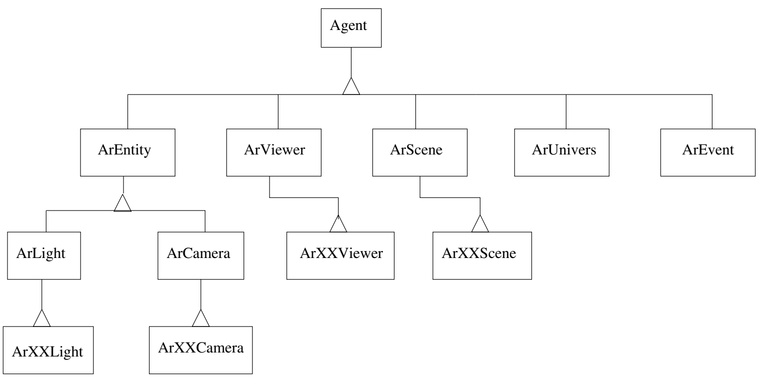

Fig. 2. xtr t of th *ARéVi* k rn l di gr m

3.3 oRis Language

s not d in S t 2 th multi g nt form lism s w ll s th dyn mi nd g n ri h r t risti s of l ngu g r v ry int r sting ro rti s in virtu l r lity syst m ont xt

mong th xisting int r r t d l ngu g s (for th dyn mi s ts w onsid r two t gori s

1 ulti g nt l ngu g s
2 " n r l" l ngu g s (mor r is ly o j t ori nt d l ngu g s

Multiagent Languages. ost of th xisting multi g nt syst ms r d v lo d for v ry rti ul r li tion ow v r mor g n r l syst ms xist too ri fly d s ri two of th m

St rlogo 18 is simul tor nd l ngu g llowing multi g nt univ rs d s ri tion h g nt from this univ rs is quiv l nt to Logo turtl whos h vior is sily s ifi d y th us r th nks to th l ngu g h s g nts mov in 2 univ rs m t ri liz d y squ r s whi h n h v h vior simil r to th turtl 's (x t for th ir ility to mov or x m l this tool giv s th ossi ility to simul t ro d tr t rmit oloni s nd food oll ting y nts ll ggr g tion r y/ r d tor osyst ms h im of su h tool is to und rlin diff r nt w y of thinking th d t ro ssing ro l m (strongly r ll l ro h Simul tions with St rlogo im l m nt hundr ds or v n thous nds of g nts

h nvironm nt 17 m k s it ossi l to d s ri multi g nt syst ms y im l m nting diff r nt l ngu g s d t d to h l v l of d s ri tion or d ision m king th LL l ngu g s d on rul s giv s th ility to d s ri g nts wh r s l ngu g s su h s ++ ommonLis nd v giv th ility to d s ri th low l v l rogr ss of h h vior l m nt ry ro ss ommuni tion tw n g nts m y syn hronous or syn hronous ut n g nt nnot tot lly ontrol noth r g nt (for x m l d stroy it nfortun t ly known li tions of this l ngu g only im l m nt sm ll num r of g nts

General Languages. n th r st of th r ov rd finition m ns dir tly h nging th od of n xisting m thod

n r l l ngu g s r o n d nough to llow th r r s nt tion of ny univ rs f th l ngu g in lud s o j t on ts th n it is r l tiv ly sim l to r h th g nt l v l y r - rogr mming "s h dul r" his s h dul r is in h rg of w king u in y li l w y h o j t whi h th n om s n g nt 7

Som l ngu g s (rti ul rly v h v som int r sting dyn mi ro rti s t ny tim it is ossi l without sto ing th int r r t r to r iv som od through th n twork nd to x ut it his od m y ont in tions (m thod tiv tions s w ll s th d finition of n w l ss s or th ov rd finition of m thods of lr dy xisting l ss s his dyn mi s t of th l ngu g

would rtly llow us to r liz wh t w w nt to do modify th ntity's h vior or dd n w ntiti s wh n x uting ut th gr nul rity of th s tions is sit- u t d on th l ss l v l or mor fr dom w would lik to h v gr nul rity on th inst n l v l w nt to l to r -d fin m thod not only on th l ss l v l thus for ll th inst n s t th s m tim ut lso for singl inst n his singl inst n will in w y slightly om d t h d from its origin l l ss or x m l l t's onsid r virtu l univ rs m d u of ro d with rs r ing on it h rs m y inst n s from th s m l ss rovid d y th r tor of this univ rs noth r rson onn ting to th s ssion m y o s rv th volution of th r nd find it not r lly s tisf tory h n h h s th o ortunity without sto ing th ro ss to hoos on r to sugg st only for this r n w lgorithm of driving nd to o s rv th w y this v hi l is ting om r d to th oth rs f th n w ro h is onsid r d to tt r th lgorithm of iloting m y th n h ng d from st tus of m thods for on inst n to st tus of m thods of l ss so s to l t ll th inst n s n fit from it noth r x m l for th us of inst n m thod ov rd finition is giv n S t 4 3

Sin th r viously quot d l ngu g s do not tot lly fulfill our r str ints w h v d v lo d our own l ngu g th *oRis* l ngu g 13

oRis Main Characteristics. *oRis* is multi g nt l ngu g t is o j t ori- nt d (l ss s with ttri ut s nd m thods multi l inh rit n h synt x is los to ++ t is lso n g nt l ngu g v ry o j t with `void main(void)` m thod om s n g nt his m thod is y li lly x ut d y th syst m s h dul r nd thus ont ins th ntity h vior

oRis is dyn mi l ngu g it is l wh n x uting to t n w od d fin n w l ss h ng th m thod's od on th l ss l v l s w ll s on th inst n l v l t is lso ossi l to dd on th inst n l v l th d finition of n w m thod whi h do s not xist in th origin l l ss

oRis llows d ou ling with ++ th rogr mm r n s ify onn - tion tw n n *oRis* l ss nd ++ l ss h ++ o j t whi h r r s nts th *oRis* g nt in th int r r t r is th o j t ro os d y th us r (d riving from th ++ g nt l ss sis l ss for th *oRis* g nts h ll of n tiv *oRis* m thod trigg rs th sso i t d ++ m thod

oRis is o n d to oth r l ngu g s r lr dy l to ll Prolog r di- t s 22 or uzzy rul s insid n *oRis* rogr m to r t r tiv nd ognitiv g nts

oRis w s su ssfully us d in li tions s v ri d s im g ro ssing 2 immunology 3 d t ro ssing n tworks 4 or ins t o ul tions 16

Integration to ARéVi. h nks to th *oRis* ↔ ++ ou ling *ARéVi* off rs th us r r d fin d *oRis* l ss s (n tiv m thods whi h orr s ond to th r - viously r s nt d ++ l ss s (S t 3 2 `ArEntity` `ArScene` `ArViewer` t igur 3 r r s nts th di gr m of th m in r d fin d l ss s his di - gr m is th x t r fl tion of th ++ l ss s (ig 2

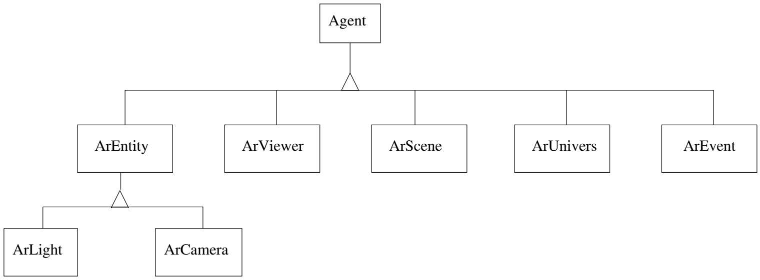

Fig. 3. di gr m of th *oRis* r d fin d l ss s for R i

Not ll th l m nts m ni ul t d y *ARéVi* r g nts not only th " hys- i l" `ArEntity` o j ts from th univ rs ut lso th stru tur s n d d for th simul tion s tting h m in dv nt g of this ro h is th t it is sy y d riv tion to giv th m h vior or x m l origin lly th `ArScene` g nt is only list of g nts whi h r visu liz d wh n w t hing th s n ith *oRis* it is ossi l to r t `ProxyScene` d riv d from n `ArScene` roviding h v- ior through `main()` m thod or x m l this h vior m y th utom ti int gr tion to th s n of ny virtu l o j t (ny g nt d riv d from `ArEntity` nt ring th on rn d zon n th s m w y n *ARéVi* vi w r (`ArViewer` h s ss to th fr m r t n v ry sily r t vi w r whos h vior is to r du th g n r t d im g qu lity (wir t if th r t om s too low n th n d t th r nd ring l v l to th ow r of th gr hi ngin

4 Examples

n this s tion w illustr t th R i multi g nt nd dyn mi iti s irstly w r s nt th mod ling of sim l m h nism ontinu with th r s nt tion of multi g nt v rsion of th P tri n tworks in lly w show v ry sim l w y to ou l oth r vious univ rs s th nks to th ov rd finition of m thods of inst n

4.1 Trains of Gear Wheels

wish to mod l tr in of g r wh ls h ro l m h r is not to r liz hysi l mod ling (ont t tw n th ogs ut fun tion l mod ling two g rs in ont t rot t in th o osit dir tion th ngul r s d r tio ing id nti l to th r dius r tio

h ro l m m y t kl d on g n r l oint of vi w th tr in h s four g rs g r 1 rot t s lo kwis g r 2 nti- lo kwis t

t m y t kl d on lo l w y g r *E* is n o j t (ssiv t knows its su ssor nd its r d ssor in th m h nism t n ll d (ll of m thods y its r d ssor *P* *P* indi t s to *E* how mu h it h s just rot t d s w ll s its

h r t risti s hus E is su os d to d du its own rot tion nd tr nsmit it to its su ssor th mov m nt ro g t s st y st in lly w r t n ngin g nt (it is th only g nt of this x m l whos h vior (`main` m thod is to rot t t only r m ins to " onn t" th ngin to th first g r to st rt th lin n th d stru tor od from th r l ss w sk th kill d g r to dis onn t from its r d ssor hus wh n x uting if g r is kill d y th us r th r will no mist k indu d (th r vious g r no long r tr nsmits mov m nts nd th following g rs will utom ti lly sto sin no ody sk for th m ff tiv ly g t syst m whos h vior is onsist nt with its r l-lif quiv l nt

h r vious x m l im l m nts ssiv g rs whi h r o j ts ut not g nts n ord r to g t mor r listi univ rs w n rovid th m with h vior

- S rutiniz th univ rs
- h n g r E is d t t d los y (th ddition of its r dius nd th E r dius = th dist n tw n th ntiti s
  - onn tion to E

  ⇒ utom ti lly st rt rot ting if E w s rot ting
- f w r onn t d to g r nd if th dist n from it om s too im ortant
  - is onn tion

  ⇒ utom ti lly sto rot ting

hus now y moving th g rs with n int rf ri h r l (mous or ls w r l to modify th m h nism wh n this on is moving (s ig 4

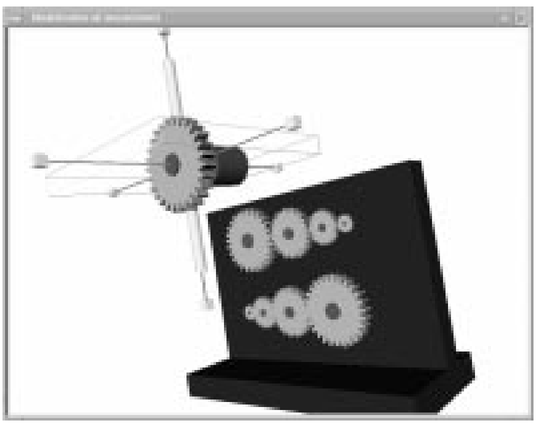

Fig. 4. rs n dyn mi lly ut in or t k n off th m h nism

4.2 Petri Networks

h s ond univ rs x m l w r s nt on rns th P tri n tworks su lly this kind of syst m do s not h v gr hi r r s nt tion ow v r w g v it on in ord r to visu liz its h vior (s ig 5 Not S v r l ro h s

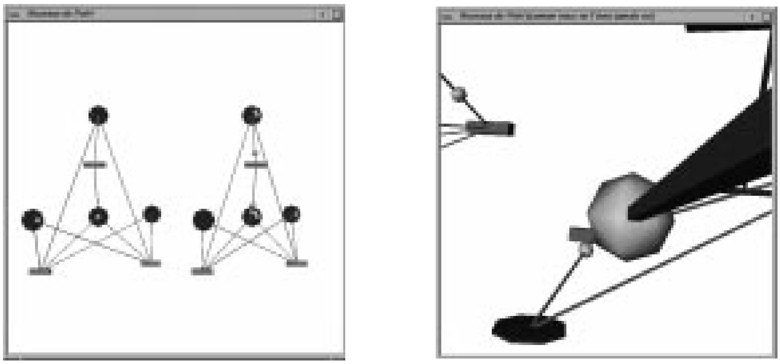

Fig. 5. r hi r r s nt tion of P tri n twork

xist for th rogr mming of P tri n tworks h n using *oRis* w h v s l t d n g nt's ro h l s onn tions nd m rks r o j ts tr nsitions r g nts h y d id th ms lv s wh n v r th y g t tiv t d it olvo t97 21

4.3 Gears and Petri Network Coupling

Now th n xt st onsists in r grou ing oth r vious x m l s in ord r for th P tri n twork to t s ontroll r for th g rs whi h thus will t s n o r tiv rt

oth univ rs s w r uilt s r t ly h r for th y don't know h oth r h ou ling is r liz d in thr st s

1 Lo ding of th g rs
2 hil th g rs r fun tioning lo ding of th P tri n tworks oth univ rs s o xist in m mory nd h v th ir own dis l y windows
3 rigg ring of th omm nd on on of th n twork l s on m rk ntr n w st rt on th ngin ou l d to th g rs n n xit m rk w swit h off this ngin

Point 3 is r liz d y dyn mi lly nt ring (without sto ing th syst m th od on (ig 6

his od ov rd fin s th ddition nd su r ssion m thods of Pl 2 h m thods r not ov rd fin d on th l ss l v l (thus for ll th inst n s ut only on rti ul r inst n l v l whi h th n do ts h vior slightly diff r nt from th oth rs

Overdefinition of a method "add" of the instance 2 from the "Place" class

```
void Place.2::add(agent mark)
{
 if (!_marks)
 {
  Engine.1->wakeUp() ;
 }
 Place::add(mark) ;
}
```

We start on the engine when the place contains at least one mark

Call of the method "add" ftom the "Place" class (common to all instances)

```
int Place.2::del(void)
{
 agent mark = Place::del() ;
 if (!_marks)
 {
   Engine.1->sleep() ;
   return (mark) ;
 }
```

We switch off the engine when place 2 is empty

Fig. 6. sso i tion of h vior to l of th P tri n twork

Not during th ov rd finition of n inst n m thod it is lw ys ossi l to ll m thod of l ss (for x m l ll of `Place::add()` in `Place.2::add()` his v ry sim ly llows to dd noth r tion to th d f ult h vior ro os d y th l ss

5 Conclusion and Perspectives

h *ARéVi* l tform uilt round th *oRis* l ngu g is d v lo ing l tform for virtu l r lity li tions t h s n su ssfully us d in s v r l industri l roj ts (rgonomi s study of t hni l uildings s d s 3 visu liz tion 3 int r tiv r r s nt tion of distri t rototy ing of m nuf turing sys- t m 8 h xist n of dyn mi multi g nt l ngu g in th syst m m k s it ossi l for us to

– r t modul r univ rs s; th modul rity is r liz d y th s n of g n r l ontroll r nd thus y th us of l m nt ry " ri ks" with th ir own go ls th g nts
– int r t fr ly in th s univ rs s; th dyn mi h r t risti s of th *oRis* l ngu g llow us s us rs to t on th low st l v l on th ntiti s (v ry- thing n g nt is l to do us r is l to do it too th n r lizing n imm rsion through th l ngu g

h r vious v rsion of th l tform did not in lud th *oRis* l ngu g ut llow d th r tion of univ rs distri ut d through th n twork 10

now work on distri ut d v rsion of *ARéVi / oRis* llowing th r rtition of g nts nd so of univ rs s through th n twork h low l v l ommuni tions r m d th nks to v nd su ort th diff r nt mod s (ni st ro d st ulti st n our roj t th hoi of this l ngu g is n lizing wh n t lk-ing out rform n s (-20 ut it off rs som v ry int r sting d v lo m nt f iliti s in t rms of sim li ity (multithr d rogr mming su ort d y this l ngu g s f ty (r - xisting grou of s f ommuni tion l ss s (v- ns int gr tion of multim di ro ssing (v di Pl y rs high l v l n twork xt nsion (s rvl ts R gl ts int ro r ility (R nd on- n tion to th d t s s (

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Investigating the Complex with Virtual Soccer

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Abstract. We describe Soccer Server, a network-based simulator of soccer that provides a virtual world enabling researchers to investigate the complex system of soccer play. We identify why soccer is such a suitable domain for the creation of this kind of virtual world, and assess how well Soccer Server performs its task. Soccer Server was used in August 1997 to stage the simulation league of the first Robotic Soccer World Cup (RoboCup), held in Nagoya, Japan. This contest attracted 29 software soccer teams, designed by researchers from ten different countries. In 1998, an updated version of Soccer Server will be used to stage the second RoboCup in France, coinciding with the real World Cup of football.

1 Introduction

ul s of so o sso i tion foot ll w fo mul t in 1 63 in t K y t oot ll sso i tion n t g m s sin om on of t most wi ly pl y in t wo l . popul ity of t g m is illust t y t following p ss g :

> ont y to popul li f t wo l 's g t st spo ting v nt in t ms of p olong wo l wi int st is not t lympi m s. t it is t o l up of foot ll w i lik t lympi s is l just on v y fou y s n is pl y out ov p io of two w ks o mo . nit t t s ost t is glo l sp t l in 1994 n w t sp t l it tu n out to . mpions ip g m tw n zil n t ly w s witn ss liv y ow of ov 100 000 p opl in t os owl in s n lifo ni n y ow of t l st illion on t l vision t wo l ov .

quot t is s iption in ou int o u tion not simply us it illust t s t popul ity of so o us t pu li tion of t is p p oin i s wit n 9 t su sso to t m i n o l up. t w just s int st in t sou of t x pt not spo ts ook o n wsp p ut t op ning p g p of t op ning pt of ook on s i n : *Would-be Worlds* y o n sti sti 97 .

J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 241–253, 1998.

sti's pu pos in s i ing t foot ll o l up is to int o u t no tion of *complex systems*. oot ll is n x ll nt x mpl in t is ont xt us it is not possi l to un st n t g m y n lysing just in ivi u l pl y s. t it is t int tions in t g m ot tw n t pl y s t ms lv s n tw n t pl y s n t nvi onm nt t t t min t out om . is is t ss n of ompl x syst ms: t y sist n lysis y omposition.

s sti's li f t t t iv l of p pow ful wi sp om puting p ility ov t p st o so s p ovi us wit tool fo stu ying ompl x syst ms s ompl t ntiti s. sti ims lf sugg sts t t su omput simul tions (vi tu l wo l s woul wo l s) pl y t ol of l o to i s fo ompl x syst ms w i in ont st to mo onv ntion l s i n l o to i s llow us to xplo info m tion inst of m tt sti 97 . t is to p ovi t is kin of l o to y fo s on ompl x syst ms t t w v v lop simul tion of t g m of so . is syst m o v n l s so m t to pl y tw n two t ms of pl y p og ms n s l y n us to st g 29 t m ont st t t i st o oti o o l up (o o up) in N goy p n. n t is p p w s i o v i ntifying in p ti ul w y so is su suit l oi s simul tion o m in. lso t k to v lu t t su ss of o v monst ting t t t p op ti s of *fidelity simplicity clarity bias-free* n *tractability* tiv m su s fo ss ssing t is kin of simul tion.

2 Soccer as a Domain for Modelling

w m ny sons in t oi of so fo ou simul to . niti lly of ou s t w s t pp l t t so is fun n sily un stoo y l g num s of p opl . o impo t nt t n t is ow v w s t signi nt ll ng o y t ying to fo m lis n un st n t om in.

2.1 Soccer as a Complex System

o illust t t i ulty of t so om in l t us tu n to t is ussion of ompl x syst ms t t w st t in t nt o u tion n to sti's ook *Would-be Worlds*. n is ussing ow t o y of t ompl x mig t fo m lis sti int o u s num of t isti s s i s s t k y ompon nts of ompl x ptiv syst ms. i fly t s (1) m ium siz num of g nts t t (2) int llig nt n ptiv n (3) only v lo l info m tion. t s oul not too to onvin t t t t g m of so is v y goo t fo t s p op ti s. o s 22 g nts. is f lls omfo t ly tw n sti's x mpl s of syst ms wit l g num s of g nts (g l xi s w i v noug g nts to t t st tisti lly) n sm ll num s of g nts (onfli ts tw n two sup pow s). g nts in so lso in t llig nt n ptiv wit t pl y s on t m st iving to p fo m w ll tog t n to out m nœuv t oppon nts. in lly t info m tion in so is l ly limit s t pl y s n only s in t i tion t y f ing

Fig. 1. in ow im g of o v

n v l ommuni tion is mp ot y ist n n y t impo t n of on ling int ntions f om t oppon nts.

us un st n ing so is signi nt ll ng : it s t t isti s of ompl x syst m fo w i s sti mp sis s t xists no nt m t m ti l t o y sti 97 . ow v s w ll s ing goo x mpl of ompl x syst m not impo t nt f to lso influ n ou oi of so : t f si ility of onst u ting simul tion. x min t is qu stion low.

2.2 The Nature of Play

n of t fo most t sks in t sign of simul tion is t tion of *model* of t om in in qu stion; it is t impl m nt tion of t ul s n p in ipl s of t mo l t t p o u s t simul tion. n t is sp t w foun t t so w s v y m n l om in simply y vi tu of ing g m .

n x ll nt stu y of t n tu of pl y is giv n y uizing uizing 0 . lt oug p im ily int st in t signi n of pl y s ultu l p nom non som of t m in t isti s of pl y i nti y uizing

l v nt to ou t m . o inst n t st p op ti s of pl y i nti y uizing t t it is volunt y (o s uizing s ys l y to o is no long pl y) n t t pl y is not o in y o l lif . s p op ti s l y sugg st som kin of mo lling p o ss. uizing t n not s t t ll pl y is limit in lo lity n u tion not f tu t t m k s pl y p omising n i t fo onv ni nt simul tion.

u t g n l p op ti s i nti y uizing t t ll pl y s in ing ul s n t t pl y n p t n t nsmitt . p s n of ul s m ns t t p t of t wo k of mo lling is l y on . n in im pl m nting o v w took t simpl pp o of sing ou mo l p im ily on just t ul s of t g m . m in of t o v mo l w s t n fo mul t to llow m ximum s op fo t inv stig tion of ow t ul s of so n tu lly follow in t st w y; t t is ow to t t m t t n pl y w ll. uizing 's n l p op ty of p t ility n t nsmitt ility t n in i t s ow ou mo l n us s n i l t st fo llowing s s to inv stig t n is uss t p op ti s of t om in.

2.3 The Type of Model Represented by Soccer Server

s w sugg st ov o v mo ls t ul s of t g m of so in w y t t llows t syst m to us s t st fo s on t n tu of t om in. int ntion is t t i nt so pl y ont ol lgo it ms n t st g inst ot to is ov w i st ong . us o v n vi w s p i tiv mo l of t l tiv st ngt s of t s lgo it ms. g wit sti 97 g 2 t t t st n fo most t st t t mo l must p ss is t t it must p ovi onvin ing nsw s to t qu stions w put to it . Not t oug t t t qu stions w w nt to nsw wit o v not just w i lgo it ms p fo m tt ut lso *why* t tt lgo it ms sup io . is is ons qu n of vi wing t syst m s t st fo s ; t ultim t go l is to v n t t o y of ompl x syst ms.

s oul lso not t t lt oug t is p p on nt t s on t vi tu l wo l t y o v t o o up tou n m nts t ms lv s lso in lu omp titions fo t ms of l o ots. n ou vi w t is link is v y im po t nt sin t m ny sults t t s ow t t l wo l xp im nts n p o u sults t t oul not xp t f om simul tion lon (*e.g.* s ompson 97 ooks 6). it t is v t s i t n l t us mov on to t k t il look t ou impl m nt tion of mo l of so .

3 Soccer Server Itself

o v n l s so m t to pl y tw n two t ms of pl y p og ms (possi ly impl m nt in i nt p og mming syst ms). m t using o v is ont oll using fo m of li nt s v ommuni tion. o v p ovi s vi tu l so l (su s t on w p s nt in igu 1) n simul t s t mov m nts of pl y s n ll. li nt p og m

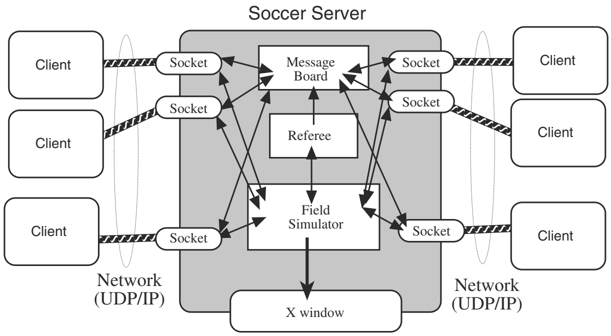

Fig. 2. v vi w of o v

n p ovi t in' of pl y y onn ting to t o v vi omput n two k (using / so k t) n sp ifying tions fo t t pl y to y out. n tu n t li nt iv s info m tion f om t pl y 's s nso s. igu 2 giv s n ov vi w of ow t o v ommuni t s wit li nts. t m in mo ul s in t o v its lf :

1. **A field simulator module**. is t s t si vi tu l wo l of t so l n l ul t s t mov m nts of o j ts king fo ollisions.
2. **A referee module**. is nsu s t t t ul s of t g m follow .
3. **A message-board module**. is m n g s t ommuni tion tw n t li nt p og ms.

low w giv n ov vi w of of t s mo ul s. mo t il s iption of t o v n foun in No *et al* 9 . lso l g oll tion of l t m t i l in lu ing sou s n full m nu ls is m int in t t o v om p g : `http://ci.etl.go.jp/~noda/soccer/server`.

3.1 Simulator Module: The Basic Virtual World

so l n ll o j ts on it 2 im nsion l. is m ns t t unlik in l foot ll t ll nnot ki k in t i n t pl y s nnot m k us of skills su s ing o voll ying. siz of t l m su in t notion l int n l quiv l nt of m t s is 10 m × 6 m. n t l t o j ts t t mov (t pl y s n t ll) n o j ts t t st tion y (fl gs lin s n go ls). st tion y o j ts s v s l n m ks t t li nts n m k us of to t min t i pl y 's position o i nt tion o sp n i tion of mov m nt. li nts not giv n info m tion on t solut positions of t i own pl y s ut only on t l tiv lo tion of ot o j ts. us t x o j ts impo t nt f n points fo t li nt p og ms' l ul tions.

ll ommuni tion tw n t s v n li nt is in t fo m of st ings. fo li nts n liz in ny p og mming nvi onm nt on ny it tu t t s t f iliti s of / so k ts n st ing m nipul tion. p oto ol of t ommuni tion onsists of:

- **Control commands**: ss g s s nt f om li nt to t s v to ont ol t li nt's pl y . si omm n s turn dash n kick. om muni tion is on u t t oug t say omm n n p ivil g go li li nt n lso tt mpt to catch t ll. sense_body omm n p o vi s f k on li nt st tus su s st min n sp n change_view s l ts t o tw n qu lity of visu l t n f qu n y of up t .
- **Sensor information**: ss g s s nt f om t s v to li nt s i ing t u nt st t of t g m f om t vi wpoint of t li nt's pl y . two typ s of info m tion visu l (see) n u ito y (hear) info m tion.

o v is is t simul tion of ontinuous tim . us ot t ont ol omm n s n t s nso info m tion p o ss wit in f m wo k of simul to st ps'. l ngt of t y l tw n t p o ssing st ps fo t ont ol omm n s is 100ms w s t l ngt of t st p y l fo t s nso info m tion is t min y t most nt change_view omm n issu y li nt (w is uss t timing of t s st ps in mo t il in §4). Not t t ll pl y s v i nti l iliti s (st ngt n u y of ki king st min s nsing) so t t t nti i n in p fo m n of t ms iv s f om t tiv us of t ont ol omm n s n s nso info m tion n sp i lly f om t ility to p o u oll o tiv viou tw n multipl li nts.

s n l f tu w n invok wit t -coach option t s v p ovi s n xt so k t fo p ivil g li nt (ll o li nt) t t s t ility to i t ll sp ts of t g m . o li nt n mov ll o j ts i t t f mo ul to m k isions n nnoun m ss g s to ll li nts. is f ility is xt m ly us ful fo tuning n ugging li nt p og ms w i usu lly involv s p t t sting of t vio s of t li nts in m ny situ tions. n xt nsion ing onsi fo fu t v sions of o v is mo i v sion of t -coach option t t llows t ms to in lu tw lft li nt t t s glo l vi w of t g m n n on u t si lin o ing u ing pl y y s outing st t gi o t ti l vi to pl y s.

3.2 Referee Module: Playing by the Rules

f mo ul monito s t g m n s in l so gul t s t flow of pl y y m king num of isions s on t ul s of t g m (n noun ing go ls t ow ins o n ki ks n go l ki ks n tim k ping). n t st o o up tou n m nt t f m no isions out fouls. n w v sion of o v ow v int o u s n o si ul ing to t possi l ju gm nts of t f . m ining fouls lik o st u tion' i ult to ju g utom ti lly s t y on n pl y s' int ntions. s v t fo lso in lu s n int f llowing um n us to inst u t t f to w f ki k. in su isions out f i pl y tu lly ll fo signi nt un st n ing of t g m futu v sions of o v m y in lu i t so k t fo f li nts t us n ou ging s on utom ti f ing.

3.3 Message Board Module: Communication Protocol

m ss g o mo ul is sponsi l fo m n ging t ommuni tion tw n t pl y s. si p in ipl of o v is t t li nt s oul ont ol just on pl y n t t ommuni tion tw n in ivi u l li nts s oul only i out vi t `say` n `hear` p oto ols int o u in §3.1.

n `say` omm n is issu t m ss g is o st to *all* li nts imm i t ly s u ito y info m tion. n ly v sions of o v t ms oul us t is ommuni tion to si st p t lo l n tu of info m tion in t g m y fo x mpl ving pl y o st is own lo tion n int p t tion of t g m t tim st p. not possi l st t gy w s to us on li nt in t m (*e.g.* pt in') to i t n info m ll t ot s. n t u nt o v ow v not ll t ot li nts gu nt to ll t o st info m tion sin t is m ximum ng of ommuni tion of 0m n ny pl y n only on m ss g f om t m u ing two simul tion y l s. lso t l ngt of t m ss g its lf is st i t . us tiv n i nt us of t `say` omm n is n ou g imp ting info m tion only w n it is us ful n tim ly.

Not t t t s v n onn t wit up to 22 li nts ut t t to f ilit t t sting it is possi l fo singl p og m to ont ol multipl pl y s (y st lis ing multipl so k t onn tions). n omp titiv situ tion su s o o up su p og ms only p mitt on t un st n ing t t t ont ol of pl y is s p t logi lly. n p ti it is lso not t ni lly i ult to t t s v n st lis int li nt ommuni tion outsi t s v so t on li nt on pl y ' ul is tiv ly g ntl m ns' g m nt.

3.4 Uncertainty

n o to fl t t n tu of t l wo l t s v int o u s v ious typ s of un t inty into t simul tion s follows:

- Nois to t mov m nt of o j ts. mount of t is nois in s s wit t sp of t o j t.
- Nois to omm n p m t s. m ll n om num s to t p m t s of omm n s s nt f om li nts.
- Limit omm n x ution. s v x ut s only on omm n fo pl y in simul tion y l . li nt p og m n g t f k on ow m ny omm n s its pl y s x ut vi us of t `sense_body` omm n (*successful* x ution must of ou s monito y t li nts t ms lv s; fo inst n `dash` s no t if pl y 's p t is lo k).
- n x t s nsing. fu t n o j t t l ss li l t info m tion tu n out it f om t s v .

p s n of t s un t inti s nfo s t impo t n of o ust v io n of t tiv monito ing of t out om s of pl y 's tions.

4 Assessing the Soccer Server

ow n w m ningfully ss ss t o v ? n §2.3 w sugg st t t t m in t st of goo mo l is w t it p ovi s nsw s to t qu stions w sk of it. us sin w onst u t o v to n l t inv stig tion of so w oul simply x min t qu lity of t on lusions l n out g nt viou in t om in. ow v mo fun m nt l vi w is lso possi l . o inst n sti 97 g 17 176 summ is s s v l p op ti s t t n us to ss ss mo ls n simul tions:

– **Fidelity**. mo l's ility to p s nt lity to t g n ss y to nsw t qu stions fo w i t mo l w s onst u t ;
– **Simplicity**. l v l of ompl t n ss of t mo l in t ms of ow sm ll t mo l is in t ings lik num of v i l s ompl xity of int onn tions mong su syst ms n num of *ad hoc* ypot s s ssum ;
– **Clarity**. s wit w i on n un st n t mo l n t p i tions/ xpl n tions it o s fo l wo l p nom n .
– **Bias-free**. g to w i t mo l is f of p ju i s of t mo l ving not ing to o wit t pu po t fo us o pu pos of t mo l.
– **Tractability**. l v l of omputing sou s n to o t in t p i tions n /o xpl n tions o y t mo l.

Not t t t s qu liti s mo su tl t n simply ss ssing w t mo l f it fully ptu s ll sp ts of t p nom non it p s nts. L t us x min t sults of v lu ting o v g inst of t it i .

4.1 Fidelity

n of t most impo t nt onsi tions u ing t v lopm nt of o v w s t l v l of st tion fo p s nting t li nt omm n s n t s nso info m tion. n possi ility w s low l v l p ysi l s iption fo x mpl llowing pow v lu s fo iv moto s to sp i . ow v it w s f lt t t su p s nt tion woul on nt t us s' tt ntion too mu on t tu l ont ol of pl y s' tions l g ting t u inv stig tion of t multi g nt n tu of t m pl y to t l v l of s on y o j tiv . u t it is i ult to sign low l v l s iption t t is not impli itly s on sp i notion of o ot w ; fo x mpl ont ol of sp y iv moto s is i s tow s p ysi l impl m nt tion t t us s w ls. n t ot n mo st t p s nt tion m y using t ti l omm n s su s `pass-ball-to` n `block-shoot-course` woul p o u g m in w i t l wo l n tu of so om s o s u n in w i t v lopm nt of so t niqu s not y t lis y um n pl y s om s p o l m ti . us ou p s nt tion using si ont ol omm n s su s `turn` `dash` n `kick` is omp omis . o m k goo us of t v il l omm n s li nts will n to t kl ot t p o l ms of ont ol in n in ompl t info m tion yn mi nvi onm nt n lso t st w y to om in t o ts of multipl

pl y s. us w li v t t o v i v s ou go l of p ovi ing simpl t st n wit signi nt l wo l p op ti s.

oi of st tion l v l is lso l v nt to fu t qu stion t t oft n o upi us u ing t sign of o v : w t t simul to s oul sign to mo l um n so pl y o o ot so pl y. is qu stion s m ny f ts ut in g n l t solution opt in t o v is to f it ful to um n so w n v possi l . justi tions fo t is in lu t soning t t l wo l so is mo imm i t ly un stoo (n mo tt tiv) to t su l o s v n t t o ot t nology n ng w s t n tu of um n so pl y s is l g ly onst nt. lso t los t simul tion to l wo l so t mo lik ly t t knowl g quisition f om um n xp tis (*e.g.* s nk 97) will i tly ppli l . f ou s t i n s tw n l so n t mo l p s nt y t s v most not ly t 2 im nsion l n tu of t simul tion. lso t simul tion p m t s tun to m k t s v s us ful s possi l fo t v lu tion of omp ting li nt syst ms t t n to i tly fl t lity (fo x mpl t wi t of t go ls is 14.64m ou l t siz of o in y go ls us s o ing is mo i ult w n t ll nnot ki k in t i). is qu stion of w t um n so is ing i tly simul t is lso impo t nt in t ont xt of t ov ll o o up ll ng w i w is uss fu t low.

4.2 Simplicity

ultim t go l of o o up s s i in Kit no *et al* 97 is to v lop o ot so t m t t n t t zil wo l up t m . in t is go l is w ll yon u nt t nologi s t o o up initi tiv n s s i s of w ll i t su go ls t t i v l in t s o t n mi t m. mpl m nting li nts fo o v is on of t s ll ng s. o j tiv of o o up is t t s t l v l of sop isti tion of xisting t nology imp ov s t simpli ity of t simul tion s oul lt pp op i t ly.

n of t p im y on ns out simpli ity is t timing of t simul tion y l s t t gov n t p o ssing of omm n s n s nso info m tion. s n so info m tion iv y li nts is i ut t tions simpl . is is n gum nt fo m king t tim tw n info m tion up t s long t n t tim tw n tion x ution (*i.e.* ving n tion p o ssing y l t t is s o t t n t info m tion s nsing y l). f t info m tion s nsing y l om s too long t ility to t to t oppon nts' tions om s mp . n t ot n if t info m tion s nsing y l om s too s o t t n ts of tt mpting to l n n p i t t oppon nts' tions iminis . u nt l ngt s of t s tim st ps omp omis int n to st ik l n tw n t s two onfli ting go ls.

4.3 Clarity

l g num of s s v l y us o v (w v l y m ntion t t t st o o up ont st f tu 29 t ms f om t n i nt

ount i s). is is vi n t t t wo kings of o v n sily un stoo . n onsi ing t l ity' of t syst m t oug w lso v to t k into ount t s wit w i on n un st n t l ssons l n t oug t ou s of su s . o w int st in qu stions lik t sults v m g out of t t ms p o u y t st o o up ont sts? o som xt nt t nsw to t is typ of qu stion is p n nt on t o ts of t o v us s t ms lv s. ow v t o o up initi tiv qui s ll t t ms nt ing ny tou n m nt to w it p p s i ing t i pp o . s p p s s ow t t in t o igin l ont sts t p og ms t t p fo m w ll w simpl o syst ms wit littl l ning ility. o x mpl t t o o up'96 tou n m nt l in p n in Nov m 1996 t winning t m w s t g l ts w i ss nti lly li on onst ining pl y to st y wit in sm ll p t min of t pit n to oos tw n sm ll num of o p ssing i tions w n t y oul t ll. n t o o up 97 tou n m nt l in ugust 1997 on t ot n t winning t ms w mo sop isti t . winn s f om um ol t niv sity us s s soning n g nt o i nt p og mming t unn s up us info m nt l ning n t t i pl t m us n xpli it mo l of t mwo k s on joint int ntions.

s w ll s monst ting t l ity of o v it s oul point out t t som tim s t us s of t syst m n s ow lmost t opposit : t t t syst m w s not tu lly fully un stoo y t sign s t ms lv s. is pp ns w n ugs foun in t simul tion t t n xploit to t v nt g of t li nt p og ms. n x mpl of su ug w s n o in t impl m nt tion of st min . n lly t st min of pl y s s w n t pl y issu s dash omm n s t us limiting t pl y 's ility to m k fu t mov m nts. ow v it w s foun y som us s t t y using *negative* p m t s in t is omm n pl y 's st min oul in s !

fu t fl w w s foun wit t v sion of o v us fo t o o up 97 ont st in w i p o l m wit t n ling of simul tion y l s som tim s llow pl y s to ki k t ll t tim s in v y qui k su ssion t us imp ting t tim s t no m l m ximum' sp . ow v it is in t spi it of t o o up ont st t t su ugs po t to t sign s so t t ll us s wo king f om n v n footing. is spi it is lso n illust tion of t i s f n tu of o v .

4.4 Bias-Free

lt oug v lop sol ly t t l t ot ni l L o to y o v s n t su st nti lly f om t opinions n sugg stions of m ny us s. n p ti ul t is m iling list i t to is ussing o o up on w i ons nsus is usu lly fo mo ifying t mo l p s nt y t simul tion (t is m iling list v g ov 200 m ss g s p mont tw n 1997 n 199). o giv f l fo t sp of ng of t simul to is p ti l list of som of t f tu s ng sin o o up 97: t int o u tion of t `sense_body` omm n t ility to `see` t i tion t t

ot pl y s f ing t int o u tion of o si s t int o u tion of go li n mo lling of t impl m nt tion of st min . ll t s ng s sign to in s p op ti s su s t simil ity of t simul tion to t um n g m t impo t n of mo lling t oppon nts' pl y o t impo t n of mo lling t t mwo k ing p o u y li nt's own t m m t s.

u t vi n of t i s f n tu of o v is t p s n of pu li li y of o (t o o up imul tion o iv lo t t http://www.isi.edu/soar/galk/RoboCup/Libs/). s s n us t is o to lp u t v lopm nt tim of o o up li nts. om o is sp i to p ti ul situ tions w s som is g n l noug to p ovi inf st u tu fo ompl t g nts (t o fo t winning li nts f om o o up 97 is v il l). n p ti ul t iv s ont in t li s li nt' li y oll tion of low l v l fun tions int n to st t w y m ny t ils of t sks su s m int ining so k ts p sing t info m tion f om t s v n s n ing omm n s to t s v .

4.5 Tractability

o v s to simul t g m of so n ommuni t wit li nt p og m in l tim . syst m n un on o wo kst tion wit only mo st m mo y n p o sso sou s (lt oug typi lly us will lso qui t l st on fu t omput to un t t ms of li nts). mo p o l m ti limit tion on o v in p ti is t p ity of t n two k onn ting t syst m to t li nts. l g lo on t n two k n l to ollisions t t p v nt li nt omm n s ing o v o info m tion ing tu n . n som t ms t o o up 97 foun it n ss y to li t t i softw to t p ti ul on itions foun t t tou n m nt sit . ow v it is i ult to p i t t x t ts of ng s in n two k on itions so li nt p og ms wit som fl xi ility in t i int p t tion of t st t of pl y n ou g . n g n l t is m y not n v s p op ty of t syst m; t n to un st n pt tion n to op wit only lo l info m tion w two of t p im qu liti s of ompl x syst ms i nti in §2.1.

5 Conclusions: Towards a Theory of the Complex

v is uss ow t g m of so is goo x mpl of ompl x syst m w ll suit to t t sk of mo lling. lso s i n ss ss ou impl m nt tion of o v l ifying t n tu of t mo l it p s nts.

L t us los y noting t t t ll ng s p s nt y t om in of so v ntly l to it ing p opos s n w st n p o l m fo s Kit no *et al* 97 . f ou s t notion of st n p o l m s long n iving fo fo ngin ing s . isto i lly fo x mpl t pt n of t u ing st' u ing 0 fo us tt ntion on t mimi king of um n vio s t st of m in int llig n . o ntly ss s iv signi nt tt ntion g n ting impo t nt v n s in t t o y of

s lgo it ms n s ont ol s w ll s motiv ting ognitiv stu i s into t w ys t t um ns pp o t s m p o l ms (*e.g.* s L vinson *et al* 91).

o (in p ti ul ont st to ss) is yn mi l tim multi g nt syst m wit in ompl t info m tion. s o v s vi tu l wo l t t p ovi s tool fo inv stig ting su ompl x om ins. t o s t is y p ovi ing p i tiv mo l of t st ngt s of softw lgo it ms fo ont olling g nts in t s nvi onm nts. n t wo s of sti 97 o v is woul wo l t t s t p ity of s ving s l o to y wit in w i to t st t ypot s s out t p nom n it p s nts . t is ou op t t fo ompl x syst ms su s so t o ts of s s using t l o to y of o v will tify t situ tion w t p s nt t s ms to no known m t m ti l st u tu s wit in w i w n omfo t ly ommo t s iption sti 97 g 214 .

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Webots: Symbiosis Between Virtual and Real Mobile Robots

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Abstract. This paper presents Webots: a realistic mobile robot simulator allowing a straightforward transfer to real robots. The simulator currently support the Khepera mobile robot and a number of extension turrets. Both real and simulated robots can be programmed in C language using the same Khepera API, making the source code of a robot controller compatible between the simulator and the real robot. Sensor modelling for 1D and 2D cameras as well as visualisation and environment modelling are based upon the OpenGL 3D rendering library. A file format based on an extension of VRML97, used to model the environments and the robots, allows virtual robots to move autonomously on the Internet and enter the real world. Current applications include robot vision, artificial life games, robot learning, etc.

1 Introduction

utonomomou o oti p nt v y wi in lu in ont ol m in l nin volution y omputin ti i l li vi ion m n-m in int m ni l i n t . n o to inv ti t t i o t n m u o l o ot w ll o tw tool o imul tin n monito in t l vi . T i p p p nt n w n tion o mo il o ot imul to op n to t l wo l n to t nt n t. T ot o tw i t tt mpt to inv ti t t i p omi in y p opo in li ti n o imul tion n t n nition l n u o vi tu l n l o ot .

2 Real Mobile Robots

o il o ot lo omotion i i v y quippin o ot wit w l o l . o t o w l o ot ly on two in p n nt moto w l . T lin p o t o ot i iv n t v p o w l n t n ul p ult om t i n o p tw n ot w l . t w l o ot

J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 254–263, 1998.

v w l ont oll y n tu to nin t o i nt tion o t o ot n oupl o w l onn t to in l moto nin t p o t o ot. L o ot u u lly v tw n two n i t l . Two-l o ot o t n um noi . o t ou -l o ot t y to qui t pp n n yn mi o m mm li n 2 w il ix l o ot t y to imit t in t it (li t lt n t t ipo it). L o ot mu mo i ult to i n n ont ol t n w l o ot ut t y mo p omi in in t y n n l ompl x nvi onm nt (t i ou t in) w t i w l ount p t l quit un om o t l .

T K p mini- o ot 9 i 5 m i m t mo il o ot i t i ut y K-T m . . t i wi ly u o n u tion pu po . t it own 6 331 mi o- ont oll n m mo y two in p n nt moto w l n i t in - n o . t i po i l to ont ol t o ot y o - ompilin n ownlo in ny u p o m w itt n in wit t K p (ppli tion o m nt). T i p ovi to t n o n tu to o t o ot n i omp ti l wit t ot imul to . T t i t m ou o n ompil it o t l o ot o t imul to wit out n in lin o o . lt n t ly it i po i l to ont ol t o ot wit mot omput onn t to t o ot t ou i l lin . T moto w l o t o ot n t i nt po itiv o n tiv p v lu o t t t o ot n mov o w w tu n i t o l t n pin oun . T in - n o u to t t o t l oun t o ot . T y n l o u to m u t l v l o m i nt li t.

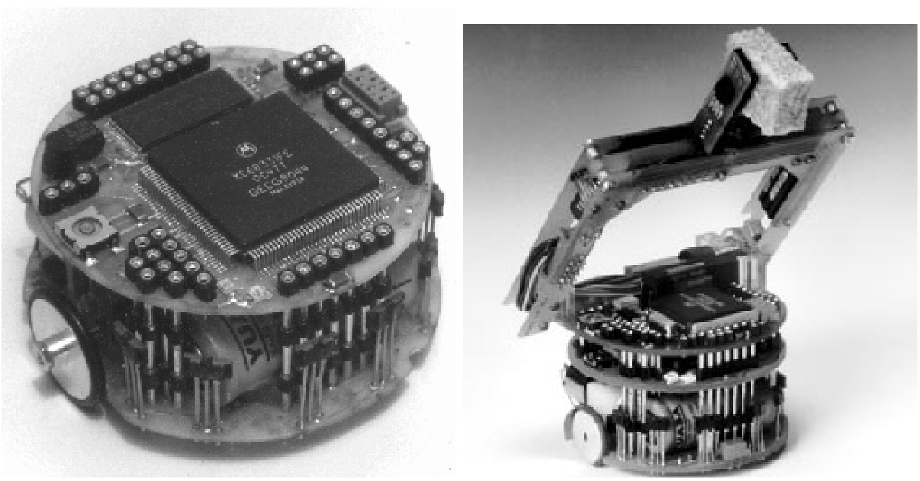


Fig. 1. L t i K p mini- o ot. i t K p quipp wit ipp tu t.

T K p o ot i xp n l num o xt n ion tu t i v il l n p ovi t o ot wit n w n o n tu to . Lin n olou m t ix vi ion tu t llow t o ot to p iv tt it nvi onm nt w il ipp tu t llow t o ot to p o j t n mov t m oun (u 2).

3 Mobile Robot Simulation

3.1 Simulation Software

o n mo u mo il o ot imul tion to v mon y n v lopm nt tim . n u imul to n u to i n t m ni l t u tu o o ot w ll to v lop int lli nt ont oll ivin t o ot . imul to p i lly pp i t w n u in omput xp n iv l o it m o l nin o volution o int lli nt ont oll . T y oul on i p ototypin tool . n t pit t t it n mon t t t t t inin o volvin o ot in t l nvi onm nt i po i l t num o t i l n to t t t y t m i ou t u o p y i l o ot u in t t inin p io .

3.2 Realism Versus Symbolism

T t o ot (o utonomou nt) imul to w i n to o v ov - ll viou (l nin volution multi- nt yn mi). n t y i n't n to mo l li ti n o n moto . T nvi onm nt mo l w l o v y impl o t n m up o i . j t w lyin on t i i n t o ot oul jump om on i qu to not . T imul to i to ym oli u n o tu n ym oli v lu li n ppl in t ov qu . n u imul tion oul ly t n to l wo l wit o ot quipp wit l n o n tu to .

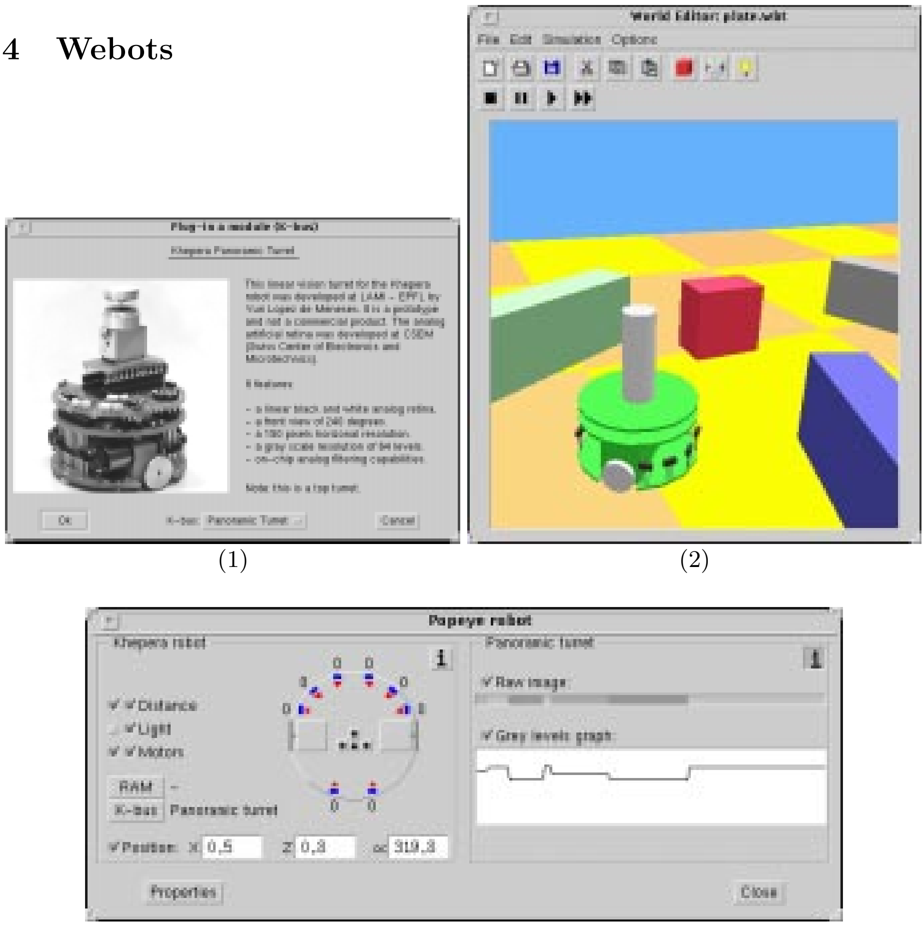
T in o omput pow p i lly in 3 p iliti llow o mo n mo p i mo l l in to mo n mo li ti imul tion . li ti imul to u u lly p i to o oti vi . om mo il o ot omp ni (li Nom i n .) v lop li ti mo il o ot imul tion n monito in o tw o t i mily o mo il o ot . ow v u imul tion o not n l vi ion n o .

3.3 Khepera Simulator

K p imul to 5 i imul tion o tw p i to t K p o ot. t li on 2 nvi onm nt mo llin . T in - n o mo ll o t t t y n n l ot li t m u m nt n o t l t tion. T u n w it p o m to ont ol t o ot. T imul to i l to iv l o ot onn t t ou t i l po t o t omput . t ny tim it i po i l to wit tw n t imul tion n t l o ot y li in on u int utton. T n t o ot ont oll t input om n n output to t l o ot. T o ot ont oll n i pl y ny t xt o p i in o m tion

in p i win ow o t t t o v n un t n w t i oin on wit t o ot. ulti- o ot imul tion uppo t . T i imul to w m v il l o on t nt n t in 1995. in t i t mo t n 1200 p opl ownlo it n m ny o t m u in it o n u tion pu po .

4 Webots



(1) (2)

(3)

Fig. 2. no mi vi ion mo ul (1) 3 n ito (2) n o ot ont ol (3)

4.1 Virtual Robots in a Network of Virtual Environments

ot i n m itiou p oj t in utonomou nt imul tion. u p limin y o l w to imp ov K p imul to y in vi ion n o mo ll wit

li ti 3 n in n in (u 4) n y op nin t imul to to ny o oti it tu (w l o ot l o ot n o ot m). T p iliti to u omp ti l ou o tw n l o ot n imul t o ot i n w int tin p p tiv in imul t o ot n y om t i l t u tu ont oll n po i ly t m mo y u o ot l to mov om on vi tu l nvi onm nt to not t ou t nt n t. n w m y on i n two o vi tu l nvi onm nt popul t y vi tu l o ot . ll t nvi onm nt woul onn t to t y vi tu l t t t o ot oul nt to mov to i t nt vi tu l nvi onm nt unnin on mot omput . n o to p opo i o t n i p oto ol llowin vi tu l o ot to mov on t nt n t t ot nition l n u w i n n xt n ion o L9 (i tu l lity o llin L n u). T on pt o lin up imul tion to t l v l o t w ol nt n t i imil to t Ti p oj t 11 .

4.2 Virtual Robots Entering the Real World

ym io i tw n vi tu l n l o ot i m po i l wit lity t . n vi tu l nvi onm nt lity t llow t vi tu l o ot to nt t l wo l vi tu l o ot nt u t it ont oll n t m mo y ownlo onto l o ot o t t t oul o t imul t o ot n nt t o y o l o ot n ontinu to un. T i i m po i l wit t K p t t n u ou o omp ti ility tw n vi tu l n l o ot . ow v o - ompil tion t i m n to y to p o u n x ut l l unnin on t l o ot. ou w y to t im- ul tion oul n in t l wo l . t n o t o w n t o ot nt it top n it ont oll n t m mo y nt to t o t omput unnin t imul t wo l . T onn tion tw n t l wo l imul tion n t nt n t lo to t on pt v lop in t l o oti y t m n oul om t o ti l i o n w ppli tion in t l op tion n u v ill n .

4.3 Realistic Sensor Modelling

n o to i v flu nt t n to t l wo l n o mo llin i n im- po t nt i u . T p o l m o t v li ity o imul tion i p ti ul ly l v nt o m t o olo i t t u m in l nin t niqu to v lop ont ol y - t m o utonomou o ot . ny t niqu m y u to i v li ti n o mo llin n u t mo l o p ti ul o ot- nvi onm nt yn m- i n uilt y mplin t l wo l t ou t n o n t tu to o t o ot 3 . ot u t i mplin p in ipl to mo l t pon o t in - n o o t K p (u 3). T p o m n p tw n t o t in viou in imul t n l nvi onm nt m y i ni ntly u y int o u in on v tiv o m o noi in t imul tion . in p o m n i o v w n t y t m i t n to t l

nvi onm nt u ul n o u t ult n o t in y ontinuin t ptiv p o in t l nvi onm nt o w mo it tion .

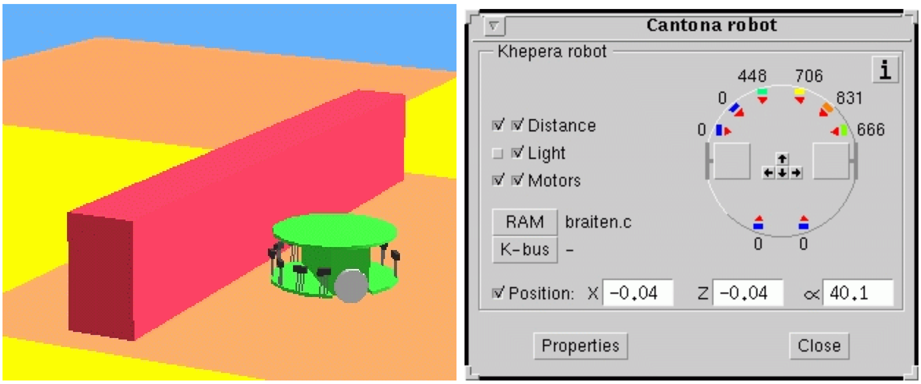


Fig. 3. n - n o mo llin o o t l t tion.

4.4 Robot Metabolism

T on pt o o ot m t oli m 6 i u ul to v lu t t viou o itu t o ot in t i t o w w y. t oul on i in o tn un tion. T o ot i iv n n initi l mount o n y o pon in to oo o l t i l pow upply. n t o ot mov u it n o n tu to m in it n y l v l lowly (no m l on umption). T n i t o ot p o m tion o x mpl ump into w ll it loo n i mount o n y (puni m nt). ut i it p o m oo tion i. . n in n onn tin to t tion it n i mount o n y (w). ow v oo n tion p - n . n t i n o t vi tu l (n l) nvi onm nt v to uil t i n io upon t i i. . m t t tion up n y only w n t o ot ul ll n it y t in t nvi onm nt o t vi t t p n t o ot (ump) w n it v w on . n t n y l v l o o ot z o t o ot i it ont oll p o m top n it t m mo y i . T n it i up to t i n o t nvi onm nt to mov t i o y (o ownlo n w ont oll n m mo y in i). T i w y it i xp t t t l tion p o will m o ot utom ti lly i pp w il oo o ot will u viv .

5 Current Applications

5.1 Vision

ynt ti i ion 10 12 o m n o mo llin ly on pow ul 3 n in li p n L. n ot n im i o t in vi p n L n in t in into ount t l o vi w li tin on ition m t i l t . T n t i im i p o to opti l i to tion n v ntu lly om n om noi . mo l o 240 p no mi m (u 4) w v lop u in two n im on ov in 120 . T i i u p n L n in n in o n't uppo t l o vi w t t n 1 0 . om m t m ti l t n o m n y to p t on im n xt to t ot in o to m p im p op ly. T m i lin t t i t ultin im on pix l i t. in it i vi p ovi in up to 64 y l v l t n L olou t n o m n ppli to t y l v l om olou im . o oti xp im nt u in ot l o ot n t ot imul to mon t t t po i l t n o ont ol l o it m 4 . t n 2 olou m mo l (wit 60 l o vi w) i l o v il l in ot .

5.2 Artificial Life Games and Robot Football

o ot m n p i lly oot ll tou n m nt tu n out to v y timu- l tin v nt o t mo il o oti ommunity. n t v iou t mo il o ot to in o to pl y oot ll v y int t- in om t point o vi w o t utonomou nt t o y omp tito mu t t o i n p in ipl o utonomou nt multi- nt oll o tion t t y qui ition m in l nin l-tim onin o oti n n o - u ion. T num o o ot oot ll tou n m nt in l ntly i quit imp iv

- utonomou o ot oot ll Tou n m nt (i ton - K uly 199 Lon on - K uly 199). http://www.dcs.qmw.ac.uk/research/ai/robot/football/ FirstARFT.html n SecondARFT.html
- oup = 6 o otiqu (L t - n - n y 199). http://www.ifitep.cicrp.jussieu.fr/coupe98.html
- ni mpion ip in o ot oot ll (u - nm m 199). http://www.daimi.aau.dk/ hhl/robotDME.html
- tiv l nt n tion l i n t T nolo i (i - n uly 199) http://www.planet.fr/techno/festival/festival98/ Robot_Footballeur.html
- i o oT (T jon - Ko uly 1996 T jon Ko un 199 i - n uly 199). http://www.fira.net, http://www.mirosot.org
- o xpo (o - witz l n 199)
- uni T ni l niv ity Tou n m nt (uni - m ny uly 199). http://wwwsiegert.informatik.tu-muenchen.de/lehre/prakt/ khepera/bericht/bericht.html

– o o up (N oy - p n u u t 199 i - n uly 199).
http://www.robocup.org

Fig. 4. o o up o l 2 x 5 K p o ot pl yin o (mo ll y . n ll)

om o t tou n m nt in lu l wo l l u w ll imul tion l u wit o i l o oti imul to . ut u u lly t o tw not l- i ti . T y o t n ly on noi - ym oli t t t woul lmo t impo i l to t om l o ot wit l n o . n t t n om imul tion to l o ot i not on i . o ov non o t imul to mo l vi ion n o w i pp to v y t on limit tion o oot ll m -pl yin . om l y t t to u ot to p p o o ot oot ll tou n m nt n ot multi- nt m . . n ll om ov niv ity (t ly) v lop o l o t o o up tou n m nt (u 5.2) n i v lopin int lli nt ont oll u in 2 olou vi ion n o v il l in ot .

6 Learning, Evolution, and Multi-Agent

in o ot l nin o t n m u o omput xp n iv l o it m . volution y l o it m w ll l nin y t m u n u l n two u u lly qui l mount o omput tion l pow w i i not lw y v il- l on l o ot . o ov o- volution o o ot p ov to l to in- t tin ult 1 . n o tun t ly w n involvin mo t n two o ot u xp im nt n ly on on l o ot . imul tion v y w ll uit o u m wo . T K p imul to o tw i o t n u to p up l nin o volution y p o . T ot o tw o n w

n o (vi ion) n n w up vi in p iliti to ilit t ompl x pow - on umin xp im nt wit volution l nin n multi- nt.

o ov wit t po i ility to t int onn t vi tu l nvi onm nt vi vi tu l t it om i l to t-up volution y xp im nt wit popul tion o vi tu l (n l) o ot o min t w ol nt n t. T i i mi t ni w y to i v v y i omput tion l pow y i t i utin xp im nt on v l m in ll ov t wo l n l t t m un only w n t ou not u t t i u in t ni t. o ov i vi tu l o ot w o t lo on t i lo l o t omput n i t t o in low i t in (i. . om t n tu l l tion point o vi w) t y oul i on t i own to mov to not omput wit mo ou v il l 11 . T i w y w oul im in t t omput on t i o t t woul wlin wit vi tu l o ot movin lowly om omput to omput to m in in t i n n n t o l omput o pow .

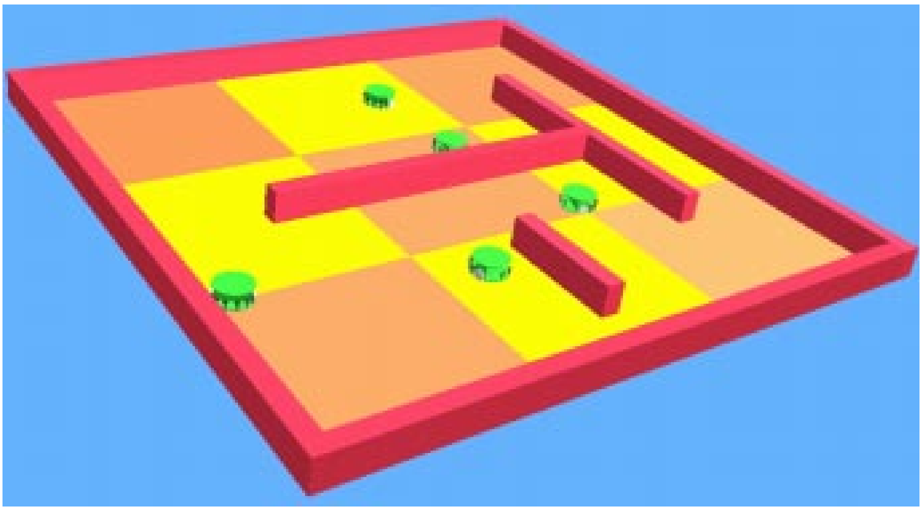


Fig. 5. ulti- o ot imul tion

7 Conclusion and Perspectives

T ot imul to t pot nti liti o v lopm nt p i lly i n ti i l m t oli m i on i . t mi t l to t m n o in o io- v o vi tu l o ot i t i ut in u -n two o int onn t vi tu l nvi onm nt . o ot volvin in t vi tu l p oul nt t l wo l ompli om mi ion n o to t nt n t in in

om in o m tion t in t l wo l . nt n t u oul int t wit t livin o ot . T y oul v t i own p t- o ot n t t m to o m ny t in (m u v ill n t l op tion). tu lly t p p tiv o v lopm nt o u t nolo y unp i t l ut w li v t ot will on on n ont i ut to t v lopm nt o ti i l li in t n t t it will p ovi pow ul tool o inv ti tion n on ont tion o ult n on t ot n it will n w im n ion to t nt n t y onn tin l o ot to n two o vi tu l wo l .

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Vision Sensors on the Webots Simulator

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Abstract This paper presents the implementation of the panoramic, linear, artificial retina EDI within the frame of the Webots mobile-robotics simulator. The structure and functioning of the simulation are presented. Realistic sensor readings and software compatibility are the two key concerns of the simulator. A realistic sensor output is obtained by modelling the physical processes underlying the sensors. Interface compatibility between the real and simulated retina has been made possible through the use of the Khepera API. The simulator is validated by running a control algorithm developed on a real robot equipped with such a vision sensor and obtaining the same behavior.

1 Introduction

imul to s h v l ys n us in mo il o oti s 6 2 3 10 . Th y llo s h s to v lop ompl x l o ithms ithout h vin to su om un li- l n som tim s xp nsiv h . ntly th possi ility o o kin ith simpl n y t li l mo il o ots su h s th h p 7 n om h s llo t p t o th mo il - o oti s s h ommunity to s it h om simul to s to l pl t o ms.

o v som s still n t om th us o mo il - o oti s simul - to s. o inst n multipl -p tn p oj ts in hi h th s h t sks is- t i ut mon s v l p tn s hil h vin sin l o oti pl t o m on hi h to t st. n th s situ tions o ot simul to s p ti l solution to fl xi ly t st th o ot in i nt nvi onm nts ut th y shoul listi nou h to llo th v lop l o ithms to us on th l o ot. noth th t n ts om o oti simul to s is volution y o oti s n o ot L n- in . xp im nts s on th pt tion p iliti s th t volution p ovi s (n ti l o ithms) o simpl l nin y n in ivi u l o ot (in o m nt L nin) n un o s v l ys o ks. Th t n sily ov th m n tim t n ilu s (MT) o th h n it n v y uous to sup vis y hum n i his int v ntion is n . Th o m ny o ks on l nin n pt tion h v n v lop on simul t o ots 10 2 .

J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 264–273, 1998.

Mo il - o oti s simul to s n ou hly l ssi into t o l ss s hi h h v n s p o sso - s simul to s n s nso - s simul to s. n th o m th o ots usu lly mov in is t o ksp h th su oun in o st l s o upy lls in th i 9 . Th o ot iv s inputs om n i h o in lls n th s inputs o t n o sym oli n tu su h s “ p son is in th ont ll . Th p o ssin p iliti s o th mo il o ot ll simul t ut not th s nso y on s. Th s simul to s v y st n th y o to - v lop ompl x l o ithms. o v th l o ithms i ult to t st on l o ots. On th oth h n s nso - s simul to s t y to mimi th spons o th s nso s to th su oun in nvi onm nt . This ui s om t i n physi l mo l o th nvi onm nt s ll s u t mo llin o th physi l p o ss s on hi h th s nso s s . Th simul t o ot mov s in ontinuous sp int p tin th s nso si n ls n i in th tions to t k n s on this in o m tion.

Th ots simul to 4 is nt x mpl o su h s nso - s simul to s o mo il o oti s. t us s n xt nsion o V ML (Vi tu l lity Mo llin L n u) to sto s iption o th o ot n its nvi onm nt n n im o th s n n o t in y usin n Op n L- omp ti l phi s li y. This in tu n llo s to simul t vision s nso s hi h h v l ys n i ult to int o u in o oti simul to s. This p p p s nts th simul tion o p ti ul vision s nso th ti i l tin ithin th ots simul to . tion 2 int o u s th ti i l tin n s tion 3 is uss s its un tion l simul tion. tion 4 ls ith n xp im nt omp in th h vio o l n simul t h p o ot uipp ith su h tin . Th on lu in m ks is uss th p oj t its ppli tions n utu o k.

2 The Panoramic, Linear, Artificial Retina EDI

Th [1] p no mi lin ti i l tin is n n lo -VL vision hip - si n y Oliv L n olt t M (u h t l itz l n) int n to v lu- t th p iliti s o su h ioinspi s nso s. Th Mi op o sso L o to y (L M) o th L is u ntly o kin on th ppli tion o su h s nso s to mo il o oti s n most p ti ul ly on h p o ot.

Th tin h s lin y o 150 photo io s lyin on n th t ov s 240 s o vi . ut s its n m su sts th is mo th n simpl vision s nso p l o t ns u in li ht. s in most nim l tin s som simpl si n l p o ssin t k s pl in th vi inity o th photo t to s still in th n lo om in. This lo l p o ssin h s th t o lt in th in o m tion u in its n i th n p ovi in th n xt st ith mo l v nt in o m tion. n s s 3 sistiv i s 11 n om in to

[1] EDI is a shorthand for ED084V2A, the CSEM’s device number.

pply lo p ss n p ss o hi hp ss lt on th im . n o -impuls - spons lt n lso ppli p o u in th iv tiv o th im . Th lt output n ss y mi op o sso th nks to th int n l / onv t p s nt on th tin . n this y 64- y-l v l im n us y th o ot o ny u th p o ssin .

Th tin h s n mount on h p tu t kno n s no mi tu t to th ith th n ss y n ill y vi s n i s i uits. Th tu t h s n in lu s plu -in mo ul in th ots simul to . Th ollo in s tion is uss s th simul tion o th no mi tu t n th tin .

Figure1. Th h p no mi tu t in o po t s n ti i l lin tin .

3 The Panoramic Turret on the Webots Simulator

Th simul tion o th tin ollo s its un tion l lo ks hi h omp is th opti s th photo t to s th lt s n th i it l onv sion. h lo k ill i fly is uss in th su s tions th t ollo . n l su s tion ill ov th so t int n its omp ti ility ith th l tin .

3.1 Optics

Th st st p o th simul tion is to l ul t th in i nt li ht int nsity on h photo t to . ill onsi th pix l v lu s o th Op n L n in n in s th li ht int nsity llin on th pix l su . Th l tin h s sph i mi o n l ns th t o us th im on th photos nso s hi h li on th hip s s n in u 2. lly th in i nt li ht th t h s th sili on su shoul th s m s th in i nt li ht th t hits in on th sph i mi o . T kin this hypoth sis ill t y to o t in th in i nt li ht on this in .

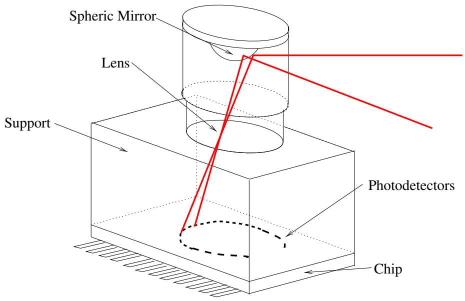

Figure2. Th opti s o th tin

Th Op n L n in n in p o u s th im o th s n s it oul s n y fl t s n m . o v th tin is sph i l s it s s n im on 240 s in zimuth n 11 s in l v tion. To solv this p o l m th 240- vi is o t in om t o 120- (zimuth) y 11 s (l v tion) p oj tions on fl t su h on p oj tin on 75 x 7 pix l y s sho n in u 3.

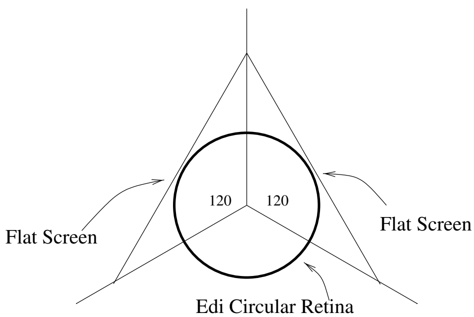

Figure3. omposition o 240- s ylin i l vi into 2 fl t vi s.

xt oth ys p y usin th t ns o m tions s it n in om u 4. Th fl t-s n oo in t s x y t ns o m into th ylin i l oo in t s ϕ n θ s un tion o th o l ist n f hi h is u l to th ius o th ylin

$$x = f \cdot \mathrm{t\ n}(\theta) \Longrightarrow \theta = \quad \mathrm{t\ n}(\tfrac{x}{f})$$

$$y = \sqrt{x^2 \quad f^2} \cdot \mathrm{t\ n}(\phi) = f \cdot \mathrm{t\ n}(\phi) \cdot \sqrt{1 \quad \mathrm{t\ n}^2(\theta)} \Longrightarrow \phi = \quad \mathrm{t\ n}(\tfrac{y}{\sqrt{x^2+f^2}})$$

v ntu lly th v ti l pix ls v to o t in t o 75 x 1 pix l v to s n th t o v to s on t n t to p o u 150 pix l v to .

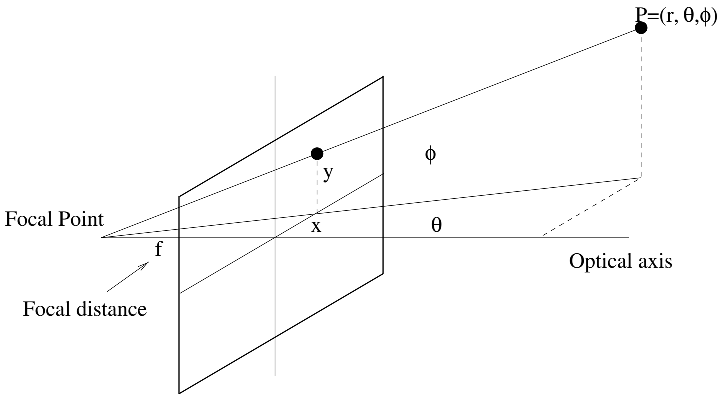

Figure4. oj tion o o l in sph i l oo in t s on to fl t s n

3.2 Photodetectors and Normalization Circuit

Th im o t in in th p vious su s tion is onsi s m su o th in i nt li ht int nsity on h o th 150 photo t to s. Th im is onv t to y s l y usin th to (lumin n) t ns o m tion o th L TV st n . This t ns o m tion iv s t in i ht to h olo h nn l. tt mo liz tion oul hi v i th sp t l spons o th photo t to s us to n t th lumin n . Th lumin n thus n t is onsi s th photo u nt on h photo io . xt no - m liz tion i uit ivi s h pix l s photo u nt y th v u nt o th hol y. This o s to o t in n illumin tion-inv i nt im th t is n im th t ill not p tu y h n s in th lo l illumin tion s ttin s o th s n . Th no m liz u nt is sto in th mo l s `analog[ ]` y.

3.3 Filtering Layer

Th lt in l y simul t s th lt in p iliti s o th ti i l tin . Th s impl m nt ith VL sistiv i usion n t o ks 11 th t n om- in to nh n th im n to xt t som h t isti tu s om it. simpl sistiv i usion n t o k h s sp ti l-lo p ss h t isti th t n us to u nois in th im n t t uni o m ions. Oth lt s n t y om inin su h n t o ks. o inst n th hi hp ss o - nh n in lt is o t in y su t tin om th o i in l im its lo p ss

v sion. Th o impuls - spons lt is n t y su t tin th output om t o uni i tion l i usion n t o ks. t p o u s th iv tiv o th input im n it n us to t t sh p s in th s n .

1- sistiv i usion n t o ks h v s lo -p ss lt s o xpon nti l impuls spons in th sp ti l n sp ti l- u n y om ins

$$h(n) = e^{\frac{-n}{\lambda}} \overset{\mathcal{F}}{\Longleftrightarrow} H(\omega) = \frac{\lambda}{\pi} \cdot \frac{1}{1+(\lambda\ \omega)^2}$$

sistiv i usion n t o ks p ll l lo lly- onn t syst ms th t p - o m omput tions on l-tim sis. This m k s it i ult to t on sin l p o sso . o v sin th syst m is m out o sisto s th t is lin vi s it n sho n th t th output is th onvolution o th input si n l ith k n l o impuls spons o th o ms th t n s n in u 5.

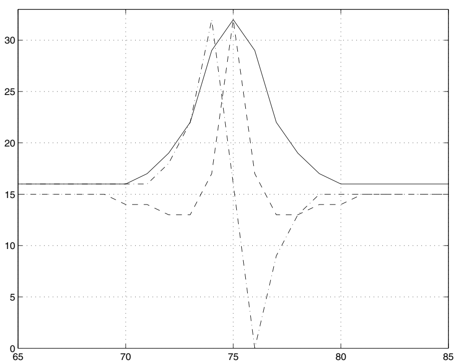

Figure5. mpuls spons s o th lo p ss (-) hi hp ss (--) n o (-.) lt s.

Th sult o onvolvin th `analog[ ]` y ith th sistiv n t o k impuls spons is sto in th `filtered[ ]` y.

3.4 Digital Conversion

Th tin h s 6- it su ssiv - pp oxim tion / onv t th t i - itiz s th output u nt om th sistiv i into 64 y l v ls. in th n lo lt s n p o u n tiv v lu s th hi h it is us s si n it. Th onv sion n y th o mul $digital = 31.5 \cdot (1 \quad \frac{filtered[\,]}{I_{bda}})$ p n s on th v i l I_{bda} hi h p s nts i s u nt on th hip. n th simul to this v i l h s n s t to v lu th t m k s th output ly s tu t h n th is sin l m xim lly ilumin t photo t to .

3.5 Software Interface: The Khepera API

Th n ts o su h s nso - s simul to oul lost i th l o ithms v lop on ots simul t o ot nnot sily ppli on l o ot. To th t n h v v lop ommon int o th l n simul t no mi tu t n h p o ot in th o m o n ppli tion o m nt th h p 5 . u h ommon int llo s th us to us th s m sou o ithout h vin to h n sin l omm on oth pl t o ms. T o i nt li i s on o th l o ot n on o th vi tu l on p ovi ith th ots simul to .

Th h p ont ins s v l un tions to ss th no mi tu - t. om un tions llo th us to n l o is l iv n lt n oth un tions us to th output o th si lt . Th on u tion un tions llo th us to s t th lt sp ti l uto - u n y th y-s l solution n th ion o int st.

4 Experiments: A Robot Regatta

To n lyz th v li ity o th ots simul to n th no mi tu t h v un on simul tion ont ol l o ithm th t s l y t i on th l h p . To o so st h to it th ol o usin h p n t st it on th l o ot. Th n ppli th sultin o to th ots simul to n o s v h th th s m h vio s o t in .

Th l o ithm om in t o i nt h vio s o t inin n m nt h vio . Th st h vio is s on it n s o st l voi n h v- io 1 usin th s nso s o th h p o ot. Th p oximity-s nso v lu s ont ol th moto omm n th ou h - o n u l n t o k s it n s n in u 6. T o i s n u ons nsu o motion o th o ot in th s n o ny -s nso stimuli. Th s on h vio is li ht s kin y usin th no mi tu t. Th o impuls - spons lt is us to o t in iv tiv o th im om hi h th li ht-int nsity lo l m xim - t t . Th o ot st s to s th m ximum (i. . li ht sou) th t is los to th nt pix l y omm n in th moto s ith si n l p opo tion l to th pix l ist n t n th li ht n th nt pix l. This moto omm n is to th n t o k output p o u in smooth t nsition om o st l voi n h vio to li ht ollo in h vio .

Th l n simul t o ots pl on s u n on hi h 3 li ht sou s o “ uoys s t o min t i n l (u 7). Th li ht uoys li t th h i ht o th tin n th o l ys visi l x pt i hi n y noth uoy. Th h p ill mov to s th uoy th t li s h n on it h s it th s nso s m k it tu n y om th li ht. o v th tin still t i s to st th o ot to s th uoy n th om in tion o

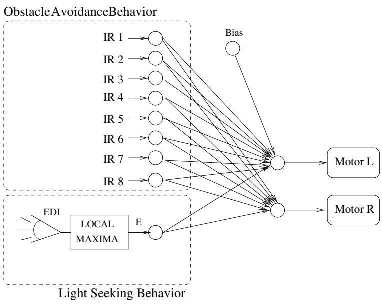

Figure6. Th n u l n t o k us in th tt xp im nt

oth omm n s m k s th o ot tu n oun th uoy until it s s n uoy lyin h . t ill thus mov om uoy to uoy s in tt . n s th is only on li ht uoy on th n th o ot ill st to s it n th n tu n n l ssly oun it.

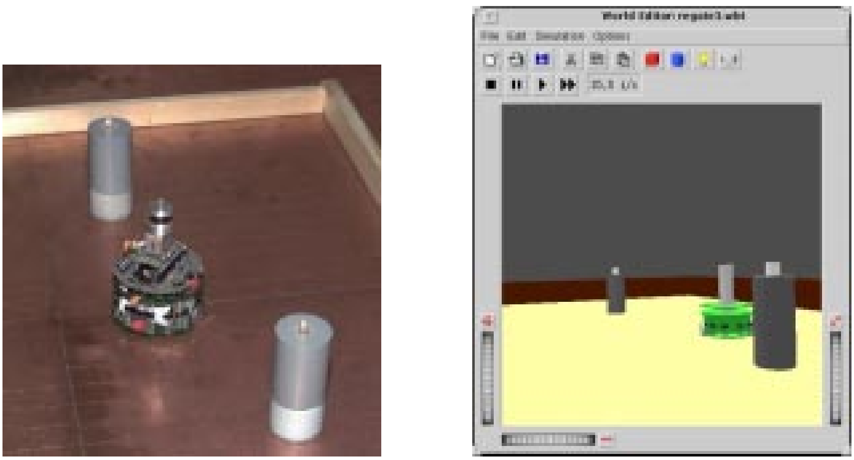

Figure7. Th l ( ) n simul t ( ) h p tt .

Th ont ol l o ithm o s not ont in s iption o th st ps to t k n h n uoy is n ount no nition o h t uoy is. t is simpl om in tion o t o simpl h vio s o st l voi n n li ht-s kin n y t n o s v th m n o n un o s n h vio th t m k s th o ot n vi t om uoy to uoy. Th m n o this n h vio p n s on th l n t n th l o ithm p m t s i. . th n t o k i hts.

n th simul t p t o th xp im nt th li ht uoys simul t s ylin s ith i ht o j t on top o th m (u 7). Th s m sou - o p o m is o nlo on th simul t h p n th s m h vio n o s v th h p mov s om uoy to uoy ithout unnin into th m n tu ns oun th li ht uoy h n th is only on on th n .

Th no mi tu t simul tion is v li t y th t th t not sin- l p m t (i. . th -n t o k i hts n th n l -to-sp onst nt o th li ht-s kin h vio) o th l ont oll h to h n . o v simul t h vio los to th l on is o t in i th -n t o k in is ou l . This o u s us th l uoys ov ith - fl tin lm to llo th o ot to s ns th m o m hi h ist n sin th ylin i sh p n th m t i l om hi h th uoys m p o u sm ll oss- s tion. Th t th t listi h vio is o t in h n fl tin inst fl t su s ms to suppo t this hypoth sis. in - fl tin o tin s not simul t in th ots simul to th s nso s nsitivity o th n t o k in h v to ou l to llo th simul t o ot to t t th uoys t th s m ist n s in th l xp im nt. This vi n in i t s th t th ots simul to mo ls listi lly th -s nso spons s.

5 Conclusion

Th p p s i s th mo llin o vision s nso ithin th m o th - ots mo il - o oti s simul to . t h s n iv n to mo l th physi l p o ss s un lyin th s nso to o t in listi s nso in . Th s nso p s nt in this p p is v y p ti ul on sin th ti i l tin is lin p no mi (i. . sph i) s nso ith si n l p o ssin p iliti s. o - v th s m p in ipl s n ppli to simul t oth vision s nso s n st n m s. Th h p s omm i lly v il l 213 vision tu t is u ntly in v lop in th ots simul to lon th s m lin .

Ou s on on n in v lopin th simul t tin n tu t s so t- omp ti ility. s simul to s s tool o th tim - onsumin v l- opm nt o ompl x l o ithms n o sh in t n sults mon i nt s h t ms. n oth s s it is hi hly si l to l to t st th l o- ithm on l o ot n to sily o so th o shoul omp ti l . o th ots simul to n ppli tion p o m int ( ) h s n n llo in to int th l n simul t h p o ot n its tu ts ith th s m sou o .

simpl xp im nt h s n us to v li t th simul t n th ots simul to . monst tion p o m th t h p viously n un on l h p o ot h s n t st on th ots simul to . l to p o u th s m h vio ithout h vin to h n sin l p m t o th

o ot ont oll . mo tho ou h v li tion oul ui volvin th s m h vio on l n simul t o ot.

Th ots simul to n th no mi tu t u ntly in us in l n m k-n vi tion xp im nt. Th simul to is us to p ti lly t in th o ot n v ntu lly th volv ont oll ill t ns to th l h p o n l sho t l nin st . Th su ss o su h xp im nt ill u th p ov th u y o th simul to .

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ish to th nk i ni` n Olivi L n olt o th h lp ul is ussions on n lo VL i uits.

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Grounding Virtual Worlds in Reality

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Abstract

We suggest in this article a new paradigm for the representation of data, which is best suited for the real-time visualization and sonorisation of complex systems, real or simulated. The basic idea lies in the use of the garden metaphor to represent the dynamic evolution of interacting and organizing entities. In this proposal, multiagent systems are used to map between given complex systems and their *garden-like* representation, which we call *Data Gardens (DG)*. Once a satisfying mapping has been chosen, the evolution of these *Data Gardens* is then driven by the real-time arrival of data from the system to represent and by the endogenous reaction of the multiagent system, immersing the user within a visual and sonorous atmosphere from which he can gain an intuitive understanding of the system, without even focusing his attention on it. This can be applied to give life to virtual worlds by grounding them in reality using real world data.

1 Introduction

Let's imagine a virtual garden whose visual and sonorous aspects continuously change to reflect the passing of time and the evolution of weather conditions in a distant place. Looking at it or simply listening to its musical rhythm will make you feel just as if you where there, looking at your garden through the window. *'It's raining cats and dogs. Better stay home!'* Connected to real meteorological data, it really functions as a virtual window, opened on a distant reality. This is what the computer-art project called *The Garden of Chances* (*GoC* to make it short) [11] is all about. Beyond its artistic interest, we believe it to have very important implications for the representation of complex systems by means of visual and sonorous metaphors.

Keeping a close watch on meteorological data in order to secure airplanes landings, monitoring the physical condition of a patient during surgical operations, observing Stock Market fluctuations so as to determine the best options to chose, are three examples of situations where decisions are subjected to the real-time understanding of complex systems, respectively physical, biological, and social or economical. Those representation and interpretation issues are transposable for artificial complex systems such as multiagent systems, for which adequate real-time representation may provide insight into the inner mechanisms of the system at the agent level, or *topsight* [10] over the functioning of the system as a whole. Visualization in Scientific Computing (ViSC) has proven very efficient to represent huge sets of data, by the use of statistical techniques to synthesize and class data in a hierarchical way, and extract relevant

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attributes from those sets, before presenting them to the user (Fig. 1). But it has not been so successful when dealing with distributed and dynamic systems since it is based, among other things, on a delayed treatment of the data.

The basic proposal is to consider any complex system one wish to represent as a metaphorical garden, the evolution of which reflects in real-time the evolution of the system. In this paradigm, the measures made on the system are not only stored, waiting for a further statistical processing, but they are also immediately transmitted to a *Data Garden*, a virtual ecosystem with the same global dynamics as the system to represent but with a stronger visual and sonorous appeal (Fig. 1). Indeed, the garden metaphor has the interesting property to be both very complex in its functioning, and still completely familiar to anybody, enabling a very fast and intuitive perception. Moreover, it doesn't require a sustained attention, since it relies for the most part on peripheral perception mechanisms, following the same principles as those that make us perceive weather conditions effortlessly. Finally, the *Data Garden* paradigm doesn't reduce the complexity of the system to represent but transform this complexity to integrate it into a meaningful environment, creating a visual and sonorous ambient atmosphere from which to gain a continuous understanding of the studied system.

In section 2, we present the concepts of scientific visualization and we explain why they fail to satisfy the needs of complex systems representation. By contrast, we present in section 3 *The Garden of Chances*, an artistic project which succeeds in mapping numerical meteorological data in an abstract, yet meaningful, representation of the weather. We finally extend the principles developed with this project in section 4, explaining the characteristics that *Data Gardens* should share in order to prove meaningful for complex systems representation, before concluding.

2 Scientific vs. Artistic Visualization and Complex Systems

Scientific visualization on the one hand is based on quantitative information display [22], visually in most cases but also using different modalities [4]. Fig. 1 shows the classical iteration cycle of scientific visualization whereby experiments are undertaken, during which data are collected. Only afterwards are the data analyzed and visualized, which allows to draw conclusions about the experiment and design complementary experiments. The cycle then iterates. This is well fitted for a great number of applications but doesn't qualify for the representation of complex, dynamic and distributed phenomena. Painting on the other hand, considered as a system of colored graphical elements is inherently distributed and based on the organization of those elements. According to Kandinsky, “analysis reveals that there is a construction principle which is used by nature as well as by art: the different parts become alive in the whole. Put differently, the construction is indeed an organization” [15]. Furthermore, painters try, and sometimes succeed, in transmitting complex perceptive and emotional experiences to their spectators. They so establish what J. Wagensberg [23] calls a “communication of unintelligible complexities”, complexities that language and numbers cannot express since they cannot be formalized.

We're now going to analyze in further details the reasons why scientific visualization concepts appear inadequate to us for the representation of dynamic and complex data. It appears in the classical taxonomy that a processing of the data is necessary in order

to extract from huge sets of data, a restricted number of attributes that best synthesize the nature of the data. To this purpose, a great number of statistical techniques and data analysis are available that we won't detail here [3]. The results are then presented using a number of standard representations such as histograms, pie or time charts and so on. New presentation models [19] are also developed that make the visualization easier by focusing on some specific aspects of the data depending on the context. An alternative to this general scheme is when the phenomenon has physical reality and may be visualized directly or using appropriate color scales. Physical numerical simulations make a large use of this techniques, and medical visualization is a rapidly expanding domain that also exploits the same principles.

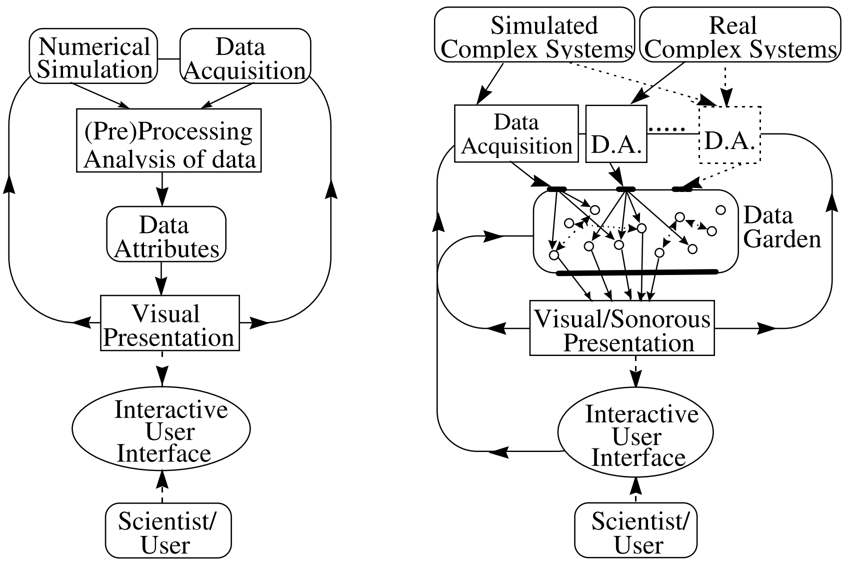

Fig. 1. Classical (partial view from [6]) vs. Data Gardens' visualization taxonomy

We propose to handle, with artistic visualization, phenomena which are both distributed and with spatial and temporal dynamicity. Our hypothesis, based on the analysis of scientific visualization techniques, is that such complex systems cannot be well represented using purely quantitative and objective means. This may be explained by the fact that we have an almost qualitative and subjective experience of such complex phenomena as meteorology, biological ecosystems, social groups, etc. Most of the knowledge that we have about those systems is derived from our everyday-life perceptions, which give us an intuitive grasp about such systems but which we don't know how to transcribe into numbers.

3 The Garden of Chances

We have explored with the computer-art *The Garden of Chances* an artistic alternative that is useful in making qualitative aspects visually or sonorously sensible in the

representation of complex systems. Furthermore, the distributed aspect of complex systems is integrated as the basis of the functioning of the project and we think it qualifies as the first step in the representation of complex systems by means of colored and sonorous metaphors.

3.1 The Artistic Paradigm

The philosophy underlying this artistic work is to let the automatic generation of images be directed by a real time incoming of real world data. This has led to the development of a first computer artwork called *Quel temps fait-il au Caplan?* (*What's the weather like in Caplan?*). In this project, weather data coming in hourly from *MétéoFrance* stations were used to suggest the climatic atmosphere of a given spot (actually a small place in Britain) by means of color variations inside an almost fixed abstract image. To put it naively, rather warm tints were used when the temperature was high, dark tints when clouds appeared to be numerous, etc. In addition to meteorological parameters, the system also took astronomical ones (season and time of the day) into account, which eventually allowed very subtle variations. When functioning continuously all year long, the animation makes the computer screen become a kind of virtual window, giving access to a very strange world, both real and poetic.

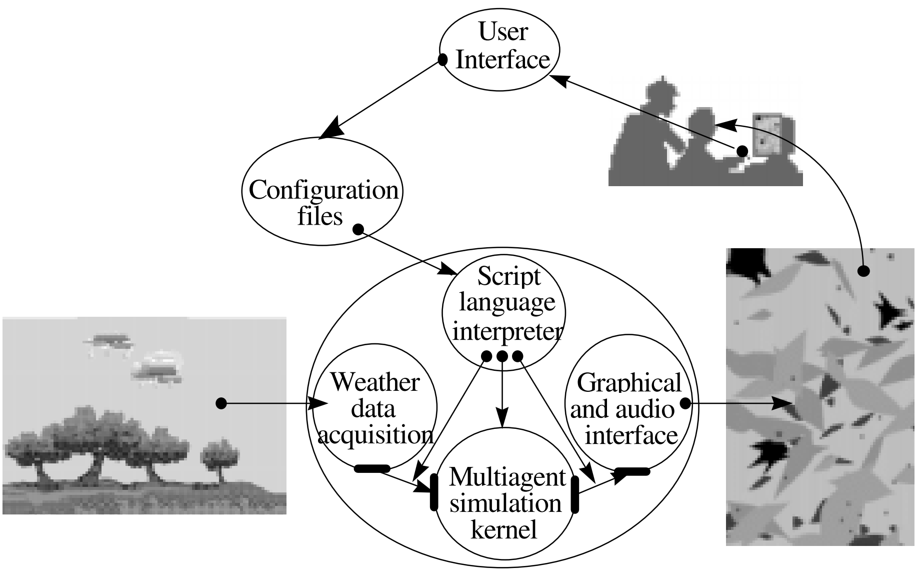

Fig. 2. The *Garden of Chances*

The *GoC* (Fig. 2) is basically designed with the same principles, namely using real data for the creation of mixed worlds, imaginary landscapes anchored in real world. In addition to colors modulations, the weather data are used to give life to a set of two-

dimensional shapes, so as to create a metaphorical representation of a real garden. Thus, each graphical creature is able to grow up like a plant, benefiting from the presence of light and rain, competing against similar or other hostile shapes, reproducing and dying like any living creature. By so doing, the goal is definitely not to produce accurate simulations of natural ecosystems nor realistic pictures of vegetation. The focus is rather put on enabling the artist to experiment with lots of different abstract worlds until he obtains some imaginary ecosystem fitting his aesthetic sensitivity. The graphical space doesn't have the passiveness of coordinate systems anymore; we rather consider it as an active principle giving birth to worlds, as the raw material from which everything is created.

3.2 The Multiagent System

In agreement with artistic requirements, the system has been implemented as a programmable platform, allowing the artist to undertake a true artistic research. Capitalizing on our experience with biological simulation systems [7], we designed it as a genuine vegetal simulation platform, supplying growth, reproduction, and interaction mechanisms similar to those observed in plants. Indeed, we believe the difference between metaphorical and simulated ecosystems only resides in the perspective adopted during the experimentation process.

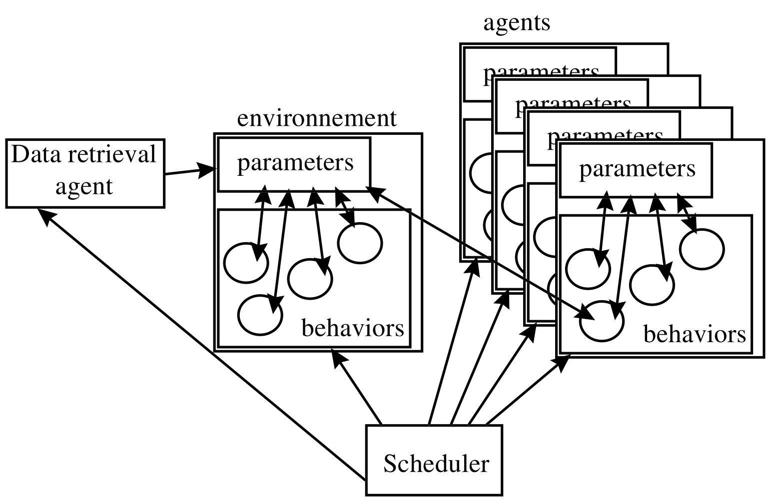

Fig. 3. The multi-agent simulation system

The core of the platform is a multiagent simulation system (see Fig. 3), representing plants as very simple *reactive agents* evolving in a simulated *environment*. Both the agents and the environment are characterized by sets of *parameters* that define their characteristics at any given time. The activity of the agents is defined as a number of *behaviors* which are programmable using a little scripting language. Those behaviors are handled by a *scheduler* which activates them whenever needed, either periodically

(each n simulation cycles) or upon reception of some particular *events* (those are related most of the time to changes in one or several parameters). Finally, agents will be represented on the screen by colored shapes, which won't have necessarily something to do with plants but may be freely designed by the artist. A given still image will thus be close to his painting work, while the dynamics of the whole system will more closely rely on the artificial side of the project, i.e. the simulation of natural processes of vegetal growth.

3.3 Agents and Environment

Parameters constitute the basis for the representation of both agents and the environment. Actually, six types of parameters have been defined in order to describe the simulated world and the incoming data flow.

Agents are characterized by reserved, internal and external parameters as shown in Fig. 4. Reserved parameters are common for all agents whereas internal and external parameters may be defined specifically for each agent. Reserved parameters include information about age, speed, color, size, etc. Internal parameters describe the resources of the agent (water, glucose, etc. with the vegetal metaphor, or any other quantifiable resource). By contrast, external parameters represent any substance or information that the agent may propagate around him (chemical substances that plants release in the soil or the atmosphere, signals, etc.).

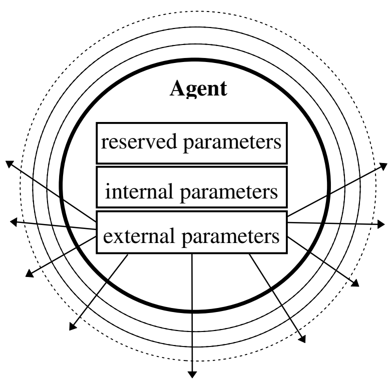

Fig. 4. Agent's parameters

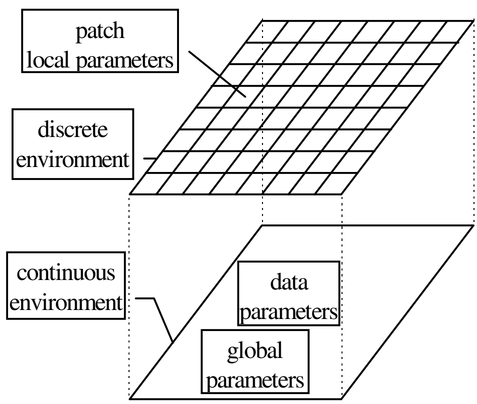

Fig. 5. Environment's parameters

The environment is characterized by local and global parameters as shown in Fig. 5. Local parameters correspond to variables whose value and evolution can be defined in a local way, i.e. for each square of the grid covering the environment (substances present in the soil, water or mineral materials for example). On the contrary, global parameters represent variables which have a nearly uniform action on the whole

environment (meteorological variables, real world data, etc.). Finally, each data variable within the incoming data flow is integrated as a data parameter.

3.4 Behaviors

A little scripting language based on Tcl has been developed in order to make the programming of behaviors easier to handle from a user's point of view. In this language, one may think about agents' and environment's parameters as local and global variables, and behaviors may be thought as procedures, either with local effects when associated to agents or with global effects when associated to the environment. Within behaviors, there are only four basic actions which can be combined together using conditional statements (if ... then ... else) and iteration loops (for ..., while ..., repeat ... until). These four actions are the modification of a parameter, the death or reproduction of the agent, and the playing of a sound file. For example, if one assumes that sun-shining conditions in a distant location are available in real-time in the data-flow and we wish to make a flower grow according to this parameter, one would have to express that some flower gains energy through photosynthesis if the sun is shining, loosing a part of this energy continuously due to its metabolism, and dying if it doesn't have any energy left. The programmed behavior would simply look like the following:

```
// parameters declaration
data_param sun_shining 3
internal_param flower energy 50 0 100

// photosynthesis behavior declaration
behavior flower photosynthesis 1
  // energy parameter modification
  param_set energy {$energy - 0.01 + $sun_shining * 0.1}
  // death if not enough energy
  goc_if {$energy == 0}
    death
    sound flower_death.au
  end_if
end_behavior
```

This approach allows to describe how some parameters evolve (slow decrease of the energy of an agent to sustain its metabolism, etc.), to specify the interactions between the agents (chemical aggressions, etc.), between an agent and its environment (water drawn from the soil to feed a plant, etc.), and even between different levels of the environment (supply of underground waters by the rain, etc.).

Behaviors are triggered by a scheduler, either with a fixed periodicity or whenever a given event occurs. An event is simply defined as a special kind of behavior which periodically evaluates a condition and positions the corresponding flag of the scheduler accordingly. In agreement with the vegetal model, different behaviors of a single agent may be triggered concurrently during a single timestep. A simulated plant

can thus simultaneously execute different operations such as drawing water from the soil, realizing photosynthesis, growing, releasing chemical substances, etc.

3.4 So What?

Set aside aesthetic and artistic discussions, the scientific evaluation of the quality of such a system proposing a metaphorical visualization of real data, would have to be done under two complementary points of view :

- what can the spectator say about the data that were used to generate the pictures ? In other words, does the representation used for visualizing the data make sense for the spectator ?
- what can the spectator say about the dynamics of the system that produced those data ? Does the representation succeeds in producing *topsight* ?

Since the *GoC* has originally been developed in an artistic perspective, experimental protocols have yet to be designed in order to scientifically address these issues. Our personal experience with the system is that meteorological variations are easily detected, but the *GoC* would surely prove not so well adapted for the visualization of any kind of data, especially when complex systems with no physical reality are concerned. We feel however that this artistic approach to both complex systems and data visualization may provide us with new paradigms for the visualization of complex data.

Without entering the details of painting creation, it should be underlined that painters are used to handling the problem of organizing distributed colored shapes in order to produce a given global effect. They are also used to evaluating and interpreting the produced result. Actually, they are used to communicating complex and subjective information by means of a visually distributed representation, and this expertise will be valuable in further development and experimentation steps. We're now going to formalize these intuitions to show how they should be integrated in a single effort to make complex interacting data accessible to direct visual perception, in what we have called *Data Gardens*.

4 Towards Data Gardens

The expression *Data Gardens* was coined in analogy with the artistic project and its garden metaphor. In fact, *Data Ecosystems* may be more appropriate, indicating any community of living and interacting organisms with graphical and/or sonic representation, whose individual survival is subjected to the real-time incoming of data to which they react, and to their interactions with other entities. Still, *Data Gardens* is strongly evocative and we will only use this expression in the remaining sections.

Data Gardens are an alternative proposal to standard schemes of data visualization which we think would be most efficient when applied to the representation of complex systems for purposes of diagnostic or monitoring. We explained in section 2 why we thought those standard schemes to be inadequate in the context of complex systems,

and we presented with *The Garden of Chances* the outline of a possible alternative. So what are the basic features that *Data Gardens* should integrate in order to fulfill the requirement of adequately representing complex systems, that is providing the user with a global understanding of the functioning of the system. And how could this be achieved ?

- As a first thing, *DG* should rely on a *dynamic* representation, necessary get a perceptive sensation of a system's dynamics and to easily detect discontinuities. This representation should be both *visual* and *sonorous*, vision being best fitted to the perception of spatial dynamics through a parallel treatment of information while audition is more adapted to the perception of temporal dynamics through sequential treatment of information. The aim is to limit the use of high-level cognitive processes, trying to take advantage of the "peripheral", rather than active, perception capabilities of the user (many experiments in augmented reality, like in the MIT MediaLab's Ambient Room [12], rely on this approach).

  The graphical and sonorous aspects of *The Garden of Chances* have been designed so that the user can interpret the painting in the same way he could interpret his daily environment for extracting critical information. Animation on the other hand is an essential part of the *GoC*, and it carries out two different kinds of information via two different dynamics: a slow, homogeneous dynamics, intended to reorganize the whole environment during a long period of time, is used to represent the seasons. Within this dynamics, a few punctual and rapid animation of some agents or sets of agents are used to represent important short-term fluctuations of the data values.

- When representing complex systems, complexity shouldn't be reduced a priori with synthetic indices and means, but should be directly integrated in the representation system. Therefore, *Data Gardens* should be based on a *multiagent modeling* (accurate or metaphoric) of the system to represent. But because complex data are generally just too complex to represent directly, distributed principles for *organizing* and *synthesizing* the represented data must be integrated, that decrease the perceptual load of the user without significantly altering the meaning of the data.

  In *Data Gardens*, incoming data influence both the activity and the evolution of the agents. The synthesis is then realized at two levels : in the individual evolution of each agent, and in the mutual interactions they engage in. The development of an agent, which is graphically translated by a modification of its shape or color, can be the consequence of the variations of different data, like the evolution of a plant within an ecosystem.

- The representation must be *metaphorical*, that is, use cognitive categories aimed at being easily interpreted and managed by the user. This is a way of decreasing the complexity, mapping abstract data into a meaningful representation from which one can get instantaneous understanding.

In that respect, one of the most interesting aspects of *Data Gardens* is the “garden” or “ecosystem” metaphor, already developed in the *GoC*. Analyzed at the light of the first two points we developed, the garden metaphor has the interesting property to have natural significance to anybody, while being very complex in its functioning. This functioning relies on the interactions of three types of complex systems: physical (the weather), biological (vegetal and animal) and social (social animals such as ants). This results in various audio-visual dynamics which look very familiar, from the slow evolution of vegetal landscapes to the fast interactions of animal life, and continuously changing meteorological ambiances.

- The representation should be *programmable*, at a user's level. The user must be able to express subjective choices about the representation, either to make it more significant with regards to data visualization, or to make it more aesthetically pleasing. Perception is a mostly individual and subjective feature of human cognitive functioning. The representation should therefore fit the user's own subjective conceptions of how the data are best visualized. Moreover, different types of representation of the same data may reveal different aspects of this data.

  In the *GoC*, the whole simulation system is programmable allowing the user to filter the input data, define the behaviors of the agents to make them react to the data, and choose their graphical representation. In the process, the user will need to be guided by the system, which should propose sets of dynamics and graphical vocabularies. Our collaboration with a painter in the *GoC* project has proven very useful for that particular matter, and we intend to cooperate more closely with various artists in order to define basic instances of *Data Gardens*.

- The representation should be *interactive* to allow dynamic exploration and perturbation of the multiagent system. Once a general framework has been found efficient, it must be made possible for the user to refine the representation acting as a kind of gardener by adding, removing, moving, changing agents on the fly. The user should also be able to visualize the system from different points of view. If the default functioning of *Data Gardens* exploits peripheral perception, the user may also choose to focus his attention on a specific part of the representation, getting then more detailed information about this part. Finally, the user should be integrated as a particular agent of the system, with extended capabilities, that would enable him to experiment the reactions of the system when perturbed.

  In the *GoC*, the basis for these interactions is set. The user can make agents reproduce, die or move, and one can view or change the parameters of agents or of the environment. When associating specific behaviors to a “perturbing agent” and when moving it around with the mouse, one can also visualize how the system may spontaneously reorganize.

- The system should finally be *evolutive*, taking into account the interactions of the user in order to learn something of his tastes and evolve accordingly. The

reason is that a given user will most of the time be unable to express how he would like the data to be represented in the formalism of the system. But if he can't formalize it, he can point out aspects of the representation that he finds pleasing or some others that he dislikes, just as in the gardener metaphor. This last point is mostly prospective for now, since nothing like it exists in the *GoC* yet.

As a result, *Data Gardens* should be designed as “meaning operators” between the flow of data and the user, who is supposed to identify and follow, in the evolution of the system, that of the outside world. However, it must be clear that they are not intended to replace the existing environments used to track and trace data (histograms, textual presentation, curves, etc.), which are still the only way to know the precise value of a variable. They are to be viewed as complementary tools that allow an instantaneous and natural perception of complex situations and propose a global perspective on them. *The Garden of Chances* is the first of such systems we built and it should now be studied in a systematic way, and with an experimental perspective, in order to develop operational design and evaluation methodologies.

5 Conclusion

We propose with *Data Gardens* hybrid environments that graphically represent information gathered in the real world for users likely to take decisions in this real world. The goal is to let a complex and dynamic system of numeric data become visually intelligible without catching the whole attention of the user. We explained how the application of DAI concepts, along with real-time visualization, allows to compensate for some of the deficiencies of more classical approaches. In particular, it enables to handle dependent data without a priori reducing the complexity of the data but only as the result of a dynamic hierarchisation and synthesis of the different pieces of the data through the organization of a multiagent system. Furthermore, the representation is evolutive and adaptive, because of its dedicated endogenous evolutionary mechanisms, and also because of the user's actions. We presented with *The Garden of Chances*, both the artistic work that initiated the reflection on *Data Gardens*, and the first concrete application of this paradigm. But it is obvious that *Data Gardens* are not limited to given data nor graphical representation types, each application domain requiring however that the representation be adapted to specific cultures and representation habits. Further work will put the focus on systematizing this adaptation process, through the constitution of libraries proposing various dynamics, based on previous works in DAI, and various graphical and sonorous schemes, based on a collaboration with artists. The aim is ultimately to be able to interpret complex and interacting systems of data, almost as naturally as one can perceive meteorological subtle variations, which could be of fundamental importance for the interpretation of multiagent systems themselves.

‘Mmm. Looks like rain has stopped. Would be perfect for a walk but it's getting cold outside and the wind has turned east. Better stay home!’

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Growing Virtual Communities in 3D Meeting Spaces

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Abstract. Most existing 3D virtual worlds are based on a "meeting-space" model, conceived as an extension of textual chat systems. An attractive 3D interface is assumed to be sufficient to encourage the emergence of a community. We look at some alternative models of virtual communities, and explore the issue of promoting community formation in a 3D meeting space. We identify some essential or desirable features needed for community formation – Identity, Expression, Building, Persistence and Focus of Interest. For each, we discuss how the requirements are met in existing text-based and 3D environments, and then show how they might be met in future 3D virtual world systems.

1 Introduction

he history o the nternet is one o d pt tion ools nd te hnologies on eived or serious purposes - ele troni m il senet the orld ide e - h ve een swi tly seized upon y ordin ry users nd used to ex h nge person l in orm tion or in orm tion rel ted to person l interests s mu h s rrier o s ientifi in orm tion the nternet is h nnel or so i l inter tions

his new underst nding o the nternet s so i l medium onstitutes si ssumption or m ny developers o rowsers or 3 virtu l worlds nvironments su h s l xxun nter tive's ommunity ryo's euxième onde nLive e hnologies' r veller nd Sony's ommunity l e re ll sed on simil r model more or less re listi visu l world in whi h people meet to so i lise hile the rowsers lso lend themselves to other uses the show se ppli tions re typi lly sed on this ide o virtu l worlds s so i l sp es; homes or virtu l ommunities th t will emerge nd exist in the ontext o the virtu l world

e intend to explore two m in issues irst we propose si l ssifi tion o some di erent types o nternet- sed ommunities his will le d us to sk some si uestions out the w ys th t 3 virtu l world systems re used nd whether those uses re lly represent the most ppropri te ones or su h systems

he se ond se tion o the p per will suggest some re uirements or systems designed to support virtu l ommunities e will look t the w y these re uirements re met in existing 3 virtu l world systems t e tures o e rlier systems

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th t might e d pted or use in 3 virtu l worlds nd t uni ue e tures o 3 virtu l worlds th t ould e exploited to pit lise on the strengths o the medium

2 Communities on the Internet

he su ess o the nternet in ostering virtu l ommunities in world in whi h re l ommunities re e oming in re singly r gmented nd unst le h s not gone unnoti ed s o Ro kwell o l xxun puts it

> " ommunity is eing seen s the long-sought 'killer pp' th t will turn the nternet into profit le resour e "

he desire to re te (nd exploit) ' ommunity' ppe rs to underlie m ny o tod y's 3 virtu l world systems he ommon h r teristi s o su h systems n e riefly st ted s ollows the 3 world is designed s virtu l meeting pl e reminis ent in some import nt w ys o our own world sers onne t inter t nd ommunity emerges he promotion o 3 virtu l world systems or this use ppe rs to e motiv ted y the ssumption th t the ' mili rity' o the world with its physi l sp es nd em odied v t rs will m ke it more essi le nd intim te th n more str t environments

here re num er o ssumptions here th t seem to re uire urther ex min tion; one import nt one is th t we n hope to m ke the virtu l world enough like the re l world th t mili rity tors will work in our vour (nd th t the overhe d o the simul tion won't work g inst us y m king the tool too slow or wkw rd to use) nother is th t inter tion in n r itr ry ontext is y itsel suffi ient to re te ommunity something whi h is not ne ess rily the se

ore su tle is the ssumption th t this is the only or the most ppropri te model or ommunity orm tion nd the est model or the ppli tion o 3 virtu l world te hnologies n the rem inder o this se tion we will ex mine some ltern tive models (shown s hem ti lly in igure) nd dis uss their impli tions or 3 virtu l worlds

2.1 Shared Interest Communities

ommon type o nternet ommunity is sed on the ex h nge o in orm tion out sh red topi o ommon interest Su h ommunity o ten lre dy exists in potenti l orm he worldwide popul tion o imi endrix ns or inst n e is potenti l net ommunity he nternet provides w y or the mem ers to ommuni te nd or the ommunity itsel - with its roles onventions nd ommuni tion p tterns - to ome into eing

ommunities o this kind re likely to e multi-mod l y whi h we me n th t they employ v riety o di erent ommuni tion h nnels voured ' ore modes' in lude m iling lists senet newsgroups nd topi -spe ifi nternet Re- l y h t (R) h nnels s the ommunity e omes est lished mem ers ex- ploit other h nnels to extend the tivity o the ommunity he ommunity

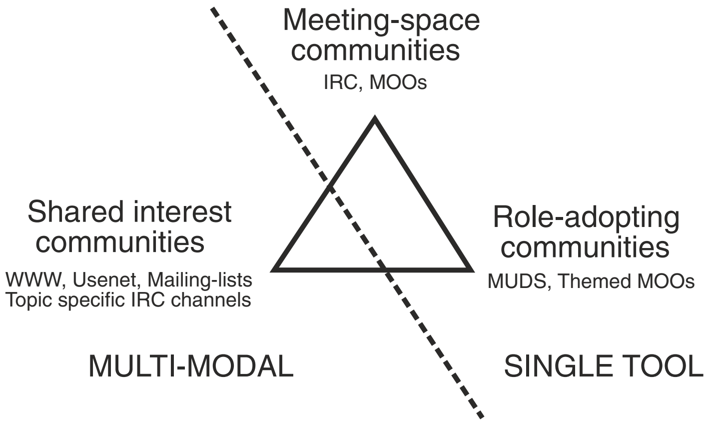

Fig. 1. ommunity types

sed round the network g me u ke or ex mple h s its own e sites R h nnels nd senet newsgroups em ers o gr phi s so tw re m iling list K List show o their work on their e sites nd ex h nge te hni ues using (n R e uiv lent) ven users o ommunity- o used h t systems m y use ltern tive h nnels; (ulti- ser imension je t- riented) users ex h nge priv te em il nd users o sever l virtu l world systems use e rings to provide ess to their worlds nd rel ted m teri ls n sense multi-mod l sh red interest ommunities re perh ps the fin l st te o ny nternet ommunity; ny su ess ul ommunity will ultim tely tend tow rds this type

n p ssing it is worth sking whether 3 virtu l worlds might not h ve role to pl y s n 'extr mode' in multi-mod l ommunities 3 worlds re typi lly presented s m in h nnel or inter tion in ommunity hey might e u lly well t s supplement ry h nnel mu h s e sites re tod y his possi ility is t present rel tively little explored or supported

2.2 Role-Adopting Communities

se ond kind o ommunity might e termed 'role- dopting' ommunity Su h ommunities re typi lly sed (t le st initi lly) round single mode o inter tion nd strong 'theme' whi h typi lly t kes the orm o story or im gin ry ontext rti ip nts ssume roles ppropri te to the ontext nd t ke re to ' t in h r ter' his is kind o 'sh red tivity' ommunity ut with the di eren e th t the sh red tivity is em edded in the medium o inter- tion sers re not using h nnel (em il) to t lk out ommon interest (imi endrix) whi h exists independently o th t h nnel; they re eng ging in n inter tion whose orm is determined y the h nnel n this tegory we in lude oth online dventure g mes (i e s) nd non-g ming environments (i e themed so i l worlds); the h r teristi e tures re the import n e o

strongly-defined ontext nd o dopting nd m int ining distin tive role or h r ter

2.3 Meeting-Space Communities

istori lly role- dopting ommunities h ve o ten evolved tow rds third kind o environment in whi h the ontext or theme is l rgely stripped w y n su h 'meeting sp e' ommunities there re no defined topi s o onvers tion nd the environment (i ny) serves prim rily de or tive purpose (lthough the onventions o the ommunity m y m ke it impolite to ignore the ontext too l t ntly see) or su h ommunity to emerge nd flourish there must e l rge num er o regul r repe t visitors who eng ge in extended inter tions ith no spe ifi sh red interest to dr w in nd ret in p rti ip nts the so i l inter tions themselves need to t s the 'glue' th t inds the ommunity together ommunities o this kind re ommonly seen in s R nd simil r h t systems hey re lso the prim ry model or 3 virtu l world systems

he t th t so m ny 3 virtu l world systems ppe r to e iming to support this kind o ommunity is interesting n the e o it one o the gre test strengths o 3 virtu l world system is its ility to re te ri h environment yet the 'meeting sp e' model l rgely ignores the environment uilding ommunity 'in v uo' is mu h more h llenging t sk th n re ting one in the ontext o sh red tivity or interest oreover e use so i l inter tions re und ment l to ommunity orm tion tools used must m ke inter tions s fluid nd expressive s possi le he m hinery needed to render 3 world is omput tion lly expensive resulting in sluggish per orm n e on ll ut the most power ul h rdw re while the h t window in whi h the inter tion t kes pl e is typi lly shrunk to minimum y ontr st n R or lient n run on lmost ny m hine nd there is nothing to t ke w y s reen sp e rom the text window in whi h the inter tion o urs

hese o serv tions r ise the ollowing uestions is the 'meeting pl e' model o ommunity ne ess rily the most ppropri te one or exploiting the potenti l o 3 virtu l worlds we dopt this model wh t n the 3 world ontri ute in terms o improved inter tion u lity whi h n justi y the extr ost o the lient re there other te hni ues we ould lso use to promote ommunity-uilding in our virtu l worlds

n the next se tion we will try to look t w ys in whi h we might m ke 3 virtu l world environments more e e tive in promoting ommunity e propose five re uirements th t we see s essenti l or desir le or ommunity orm tion or e h o these we o er justifi tion nd then ex mine how the re uirement is met in existing systems oth 3 nd 'tr dition l' e then suggest how uture 3 systems might meet the re uirement dr wing on oth 3 -spe ifi nd more gener l te hni ues

3 Promoting Community in 'Meeting Spaces'

ommunity orm tion is omplex usiness ny o the tors th t le d to the orm tion o su ess ul ommunity re int ngi le nd nnot e sily e engineered Su h tors in lude the o urren e o orm tive events (see 7) nd the ommitment or dyn mism o individu l mem ers (9 spe ks o 'keystone pl yers') hether ommunity flourishes or st gn tes will depend on the type o inter tions th t t ke pl e within it

here re however some tors th t m y e men le to ontrol 2 presents use ul list o re uirements o using hiefly on the omput tion l e - tures o the supporting environment ere we present our own list o r ther more str t re uirements lthough there will o ten e degree o overl p

riefly we elieve th t ommunity orm tion re uires th t the environment h s some i not ll o the ollowing properties users must h ve the me ns to re te distin tive identity the me ns to use non-ver l orms o expression nd the me ns to uild sp es nd o je ts he world itsel should e evolving nd persistent nd ide lly there should lso e ommon tivity or o us o interest hese re uirements re summ rized s hem ti lly in igure 2

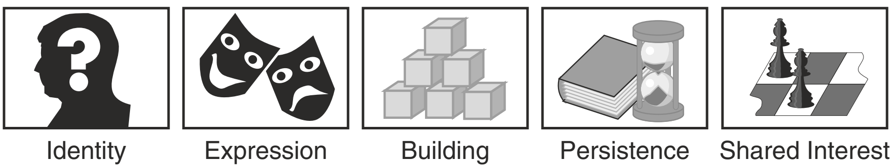

Fig. 2. ive re uirements or ommunity orm tion

3.1 Identity

ne o the first e tures th t we see s ne ess ry or the orm tion o ommunity is me h nism or mem ers to re te nd m int in n identity (not ne ess rily the s me s their re l-world identity ut nonetheless distin tive nd re ognis- le) rgues th t identity is und ment l to est lishing the rel tionships ne ess ry to ondu ting usiness nd regul ting group eh viour n in ility to present ourselves s individu ls will dire tly imp t our ility to orm so i l rel tions

dentity is multi- eted ho we re is defined y our rel tions with others y wh t we s y nd do nd y the w y we present ourselves nd y the things th t we own nd ontrol ur rel tions with others re typi lly defined in w ys th t re independent o the environment he environment m y ontri ute riti lly however in the ilities it provides or users to present themselves t is this issue we will onsider here

Identity in Other Channels striking e ture o m ny environments supporting virtu l ommunities re the limited me ns they o er or onveying identity n ele troni m il senet or nternet Rel y h t (R) p rti ip nts re judged lmost ex lusively on wh t they write premium is pl ed on u lities su h s wit rti ul y origin lity nd mili rity with sh red onventions eyond their writing users n onvey identity only through their 'h ndle' (R) or m il ddress (m il or news not lw ys under the user's ontrol) nd use o sign tures (m il or news) Surprisingly some o the most oherent nd olour ul ommunities seem to emerge in pre isely su h limited environments Restri tions m y even en our ge re tivity nd ssertion o identity

Ri her ilities re o ered y ugmented text- sed environments su h s s where users m y provide des riptions o themselves ostensi ly physi l ut o ten used to onvey something out the owner's tu l or desired personlity (see 6) Someone who des ri es themselves s *"Short, fair-haired, slightly chubby, wearing jeans and a denim jacket."* is ommuni ting something r ther di erent rom someone who des ri es themselves s *"A nervous-looking three-legged centaur wearing two Cecil the Seasick Sea-Serpent puppets on its hands."*

r phi l environments o er di erent possi ilities n 2 visu l environments su h s l e users n sele t gr phi s to represent themselves mu h s users sele t textu l des riptions hile pi ture is not ne ess rily worth thous nd words the use o gr phi s to onvey h r ter (nd s we sh ll see l ter mood) n e uite su tle nd expressive

Identity in 3D Virtual Worlds sers in 3 virtu l worlds re represented y v t rs gr phi l represent tions o their virtu l person hese v t rs re typi lly pi ked rom set o ustomis le sto k types n ortun tely the r nge o v t rs v il le is o ten very limited nd the ustomis tion possi ilities m y e too restri ted to ommuni te nything me ning ul out the owner n m ny existing 3 environments the limit tions o the v il le v t rs hinder the est lishment o ny re l identity

Improving Identity in 3D Virtual Worlds o try to m ke v t rs more 'identifi le' there re two possi le ppro hes ne is to orrow rom text- sed virtu l worlds y tt hing inspe t le textu l des riptions to v t rs tt hed des riptions n in lude ddition l met -in orm tion; sever l 3 systems support 'hyper rds' virtu l usiness rds whi h n rry n mes (re l or im gin ry) m il ddresses nd e site RLs

t the other end o the s le re te hni ues whi h m ke use o the uni ue properties o visu l 3 worlds ne possi ility is to m p the user's re l-world likeness to their v t r s either still or moving im ge (e g 3) hile this might ppe r to resolve the issue o identity in the most dire t w y possi le it is un le r how popul r it is likely to e in pr ti e; the lending o the re l nd the virtu l n sometimes d m ge the illusion nd m ny users m y pre er to present n str t im gined identity r ther th n their re l-li e ppe r n e

n ltern tive is to llow users gre ter reedom in the hoi e o v t rs ide lly y letting them design or d pt their own his will re uire some st n- d rdiz tion to ensure interoper ility n issue whi h is eing ddressed y the nivers l v t rs e ort o the R L onsortium nvironments m y need to en or e onstr ints on v t r properties in order to void n ' v t r rms r e'; the desire or gre ter sel -expression m y le d to more omplex models with n inevit le imp t on downlo d times nd r me r tes

v t r hoi e m y lso e su je t to estheti onstr ints 3 orre tly predi ts th t there re likely to e so i l st tus issues rel ted to v t r hoi e while entering strongly-themed world with n in ppropri te v t r riding sk te o rd nd we ring wr p round sh des in medi ev l stle or ex mple is likely to use o en e nd resentment

ltim tely it seems likely th t we will move tow rds truly person lised v t rs ut in the me ntime we should not negle t the potenti l o non-visu l h nnels (i e textu l des riptions nd hyper rds) whi h h ve the dv nt ge o pre ision nd expressiveness t very low ost

3.2 Expression

Su ess ul so i l inter tions depend on gre t de l more th n simply ex h ng- ing words n e-to- e onvers tions we use p r linguisti ues su h s tone- o -voi e i l expressions nd ody l ngu ge to onvey signifi nt proportion o our mess ge le troni environments whi h deny us the use o these ues n o ten impose severe onstr ints on ommuni tion we n in some w y restore these ues we m y e le to re te ri her nd more n tur l inter tions th t will en our ge so i l onding

Expression in Other Channels erh ps the est known orm o extr lin- guisti ues in online environments re the smileys used origin lly in ele troni m il nd news hese onvention lised sym ols serve lmost the s me un tion s tone o voi e with v ri tion in me ning ording to ontext he 'h ppy' smiley :-) m y me n th t the user is ple sed with some st te o irs just re erred to th t they're m king joke or more r rely to indi te gener l st te o h ppiness se to sign l jokes is widespre d p rti ul rly in ontexts when iling to per eive n utter n e s joke ould use o en e

ext users h ve other onvention l devi es v il le to them su h s use o upper se to S sterisks or emph sis et hese onventions me out e use they were needed; even ele troni m il o ten seems to e loser to onvers tion th n letter-writing nd so su stitutes were ui kly ound or the extr -linguisti m rkers we use to m ke onvers tion fluid nd un m iguous

hese devi es re lso used in R nd s/ s ut su h syn hronous inter tions o er ddition l possi ilities or expression ilities in the environ- ment su h s the 'emote' omm nd provide w ys to des ri e h r ter tions whi h re ommonly used to onvey mood or ttitude his re hes its most omplex in so i l s or s where onvers tion m y involve el or te

ritu lised use o st nd rd omm nds nd o ten humorous inter tion with o - je ts in the world (see 5)

r phi l systems su h s he l e supplement these devi es urther y use o visu l in orm tion he im ge used to represent h r ter n e swit hed t ny time nd this e ture is sometimes used to onvey mood or ttitude sers m y h ve li r ry o di erent im ges to dr w on nd sign l their st te o mind or eelings out nother user y su stituting one or n- other (em le user might present neutr l im ge to str ngers or inst n e nd more re ognis ly em le one to intim tes)

Expression in 3D Virtual Worlds 3 virtu l worlds whi h typi lly in lude text- h t element o ten dr ws on the s me onventions s ove Smileys re widely used nd in the sen e o emotes sel -des riptive utter n es re sometimes seen his m y e in p rt e use m ny 3 users h ve ome rom text- sed kground ut it m y lso e e use the expressive tools provided y the 3 environment re too rude or wkw rd to use

xpli it support or expression in 3 rowsers typi lly t kes the orm o push- utton ontrols whi h use the user's v t r to gesture or dopt - i l expression estures re 'one-o ' movements while i l expressions m y persist until su stituted y nother

xpression support in 3 virtu l worlds is pro lem ti estures nd i l expressions re o ten ex gger ted nd do not ne ess rily m p well to di erent v t r types (i your v t r is fish how do you onvey surprise or h ppiness) oreover it ppe rs th t users do not e sily mix text nd gr phi s yping joke nd then li king the smile utton to show th t you're not serious does not seem to ome n tur lly ore seriously the gesture doesn't ppe r in the written re ord; i someone re ds the inter tion l ter or misses the gesture they h ve no w y o knowing you were joking n su h ir umst n es most users will use smiley inste d

Improving Expression in 3D Virtual Worlds 3 virtu l worlds should provide us the me ns to restore some o the ody l ngu ge th t we lose in tr nsition to the ele troni environment ut in pr ti e it h s not worked th t w y v t rs in onvers tion tend to ppro h e h other orient themselves roughly tow rds e h other (ut not lw ys) nd rem in motionless throughout the inter tion No use is m de o movement or dist n e nLive e hnologies h ve ound th t the ody is lmost entirely irrelev nt nd h ve redu ed their v t rs to mere he ds e might sk wh t i nything the 3 virtu l world ontri utes to expressiveness

Re l-time video-m pping o ers one possi ility llowing users to show i l expressions oupled with voi e- r ther th n text- sed ommuni tion this would give us the possi ility to inter t more n tur lly ut t this point we ould st rt to wonder why we need virtu l world t ll ll we're interested in is spee h nd i l expressions why not use video- on eren ing

n ltern tive might e to use v t r ody l ngu ge whi h is under indire t r ther th n dire t ontrol o the user se o smiley in text ould prompt the v t r to grin moment rily sers ould set p r meters to indi te their gener l st te o mind nd the world would respond y nim ting the v t r ontinously in su h w y s to suggest the ppropri te mood oredom pprehension nxiety et (see 0) t rem ins to e seen how e e tive su h systems will e in onveying mood in re l inter tions ut i we intend to exploit the e tures o the 3 world to the m ximum this looks like use ul dire tion to explore

3.3 Building

or ommunity to orm users should h ve some kind o involvement in the world th t they o upy n h nnels th t support n expli it 'world' (3 virtu l worlds S nd s r ther th n R or em il) there seems to e n instin tive desire or users to ontri ute to the world in some w y uilding not only gives the user person l st ke in the world ut it n lso enri h the world or other users (onsider the se mentioned in 9 o user who introdu ed fish nd fishing poles to the ue lo edu tion l)

uilding is lso n tivity th t helps to orm identity nd en our ge inter- tions 'virtu l home' n reve l s mu h out us s n v t r des ription (see the des ription o r est's room in 7) re tion o use ul or interest- ing o je t gives the re tor st tus (2) while ex h nge o desir le o je ts or te hni l in orm tion m y orm the sis o inter tions with other users

uilding h s other roles je ts th t re uilt serve s t ngi le reminder o the history or the onventions o the ommunity he re tion o ver s to en psul te running jokes in s is good ex mple o this uilt o je ts m y lso serve s the o us or inter tions nd in p rti ul r or the kind o ritu lised ver l sl psti k h r teristi o s

Building in Other Channels uilding is not e ture o em il news or R Some s nd s however permit users to dd new o je ts to the world r nging rom urniture to simple utom t to sp es whi h other users n enter nd explore je ts re typi lly p rt o ull o je t-oriented system whi h llows new o je ts to inherit (or override) eh viours rom their p rent o je ts Some progr mming skill is re uired to define interesting eh viours ut the implement tion l ngu ges re gener lly simple enough th t new o je ts n e dded to the world without too mu h diffi ulty

Building in 3D Virtual Worlds he n ture o 3 virtu l worlds me ns th t uilding is likely to e more omplex th n in textu l worlds mong the 3 virtu l world systems th t do llow some kind o uilding re ryo's euxième onde nd ir le o ire's lph orld euxi eme onde provides e h user with ustomis le 'home' ut the possi ilities ppe r rel tively onstr ined nd the emph sis is on sele tion nd onfigur tion r ther th n uilding n m ny w ys this p r llels the issue o v t r hoi e dis ussed ove lph orld is

r ther more interesting; users m y re te o je ts sed on pre- uilt omponents (Renderw re R o je ts) nd ssign them properties visi ility solidity nd eh viours re tions to li ks ollisions et

Improving Building in 3D Virtual Worlds he power nd flexi ility o s rises l rgely rom the t th t the system is uilt round n o je t-oriented model whi h en our ges ode-sh ring nd re-use simil r model will pro ly e ne ess ry in the se o 3 virtu l worlds i the world is to e e sy to extend nd m int in his m y re uire onsider le h nges to the underlying r hite ture o the server nd even to the represent tion l ngu ge used or the world (see)

ppropri te uthoring tools will lso e re uired t might e desir le to integr te the tools with the rowser so s to llow the user to work dire tly with o je ts in the world r ther th n going through uild-test-edit y le

llowing the user to uild nd dd r itr ry o je ts using the ull expressive power o R L nd v (or simil rly omplex implement tion l ngu ge) poses l rge num er o signifi nt te hni l pro lems p rti ul rly where effi ien y nd st ility is on erned n the present st te o te hnology it would e ll too e sy or user to uild o je ts th t either onsumed huge u ntities o lient nd server resour es or used runtime errors on the lient Nevertheless it seems re son le to suggest th t this is the dire tion in whi h 3 virtu l worlds m y ultim tely move

3.4 Persistence

llowing uilding le ds ne ess rily to onsider tion o issues o persisten e le rly i users expend e ort in onstru ting o je ts they will expe t the o je ts to e there the next time they onne t je t- uilding implies the need or persistent stor ge me h nism to re ord ll h nges m de in the world

here n e other spe ts to persisten e s well So i l inter tions onstitute kind o persisten e the so i l group ts s 'memory' or p st events individu l identities sh red onventions nd so orth his is not something th t n e sily e engineered nd is in t dire tly rel ted to the growth o ommunity s ommunity grows it e omes persistent

ersisten e n lso e interpreted in nother w y r doxi lly persistent world is one th t evolves over time world whi h is identi l e h time we onne t to it l ks ny re l 'existen e'; it seems to exist 'outside time' nd this rozen u lity n detr t seriously rom the ppe l o the world

Persistence in Other Channels s nd s whi h support uilding implement o je t persisten e y regul r kups o the d t se y opying o je ts to king stor ge it is possi le to ensure th t r shes or server re oots will not destroy re ted o je ts

s nd s lso provide kind o support or so i l persisten e in the sh pe o news systems ssues o the d y nd ontri utions rom mem ers o the

ommunity m y e re orded in re d le orm th t onstitutes in ert in sense kind o re ent history o the ommunity

Persistence in 3D Virtual Worlds or o vious re sons only those worlds th t support m king h nges to the world h ve persistent e tures nd only or rel tively limited set o properties s r s we re w re no urrent 3 world supports the kind o r-re hing nd perv sive persistent model seen in s xpli it support or so i l persisten e (i e news systems) is typi lly provided extern lly i t ll in the orm o e p ges (the euxième onde or ex mple h s n extensive e - sed news servi e)

Improving Persistence in 3D Virtual Worlds ully o je t-oriented world model will re uire persisten e me h nisms simil r to those ound in s hile the implement tion o su h d t se systems is well-understood it remains to e seen how e sily it n e d pted to the needs o 3 worlds

ssues o so i l nd ontextu l persisten e re less te hni lly h llenging ut m y re uire new ppro h to the provision o 3 worlds n p rti ul r the t o world- uilding m y need to e seen not so mu h s one-o engineering tivity ut s pro ess o ontinuous re tion he world uilders need to provide their world with n evolving ontext in order to enh n e the user's per eption o eing *in* world whi h is onsistent nd enduring his m y involve not so mu h dding new e tures to the world s exploiting the visu l represent tion to onvey the ide o p ss ge o time d y nd night se sons even de y; in short nything th t will help to give the impression o living nd h nging world r ther th n mere model

3.5 Shared Purpose and Activity

ur l st re uirement returns us to our e rlier dis ussion o di erent ommunity types t is in some senses desired r ther th n re uired h r teristi so we sh ll not n lyse it in s mu h depth s the others he ex mple o s nd R show th t ommunities n emerge nd thrive without ny sh red tivity other th n th t o t lking to others Nevertheless o serv tion suggests th t users re likely to e more toler nt o the limit tions o tool i they h ve v lid extern l re son or using it we w nt people to use our 3 virtu l worlds inste d o the simpler swi ter h nnel o R we need to look or ppli tions in whi h the use o 3 virtu l world provides n dded v lue r ther th n merely n en um r n e

inding suit le ppli tions is wide-open rese r h re ne possi ility would e to move w y rom the 'meeting sp e' model tow rds the 'role-dopting' model nd use the power o the 3 world to re te ompelling ontext or inter tions (Sony i tures h ve m de n interesting step in this dire tion y using the Sony ommunity l e system to re te movie tie-in worlds in whi h users pl y roles sed on the film) ther ppli tions might in lude virtu l improvis tion l the tre oll or tive work using visu l elements or multimedi 'j m sessions'

4 Conclusion

urrent uses o 3 virtu l worlds re typi lly sed on 'meeting sp e' model o ommunity his is not the e siest model to exploit the p ilities o 3 worlds o en our ge ommunity growth in this ontext we must find w ys to promote so i l inter tions nd involvement in the world o do so we will need to dr w on oth existing me h nisms nd dv n ed 3 -spe ifi te hnologies to try to m ke our virtu l environment more n tur l nd ompelling

e should lso keep in mind th t su ess ul ommunities o ll kinds tend to evolve into sh red interest ommunities th t m ke use o v riety o di erent ommuni tion h nnels hen designing rowsers or 3 virtu l worlds it m y e use ul to t ke this into ount nd pl n or their use s p rt o olle tion o tools r ther th n uni ue h nnel or inter tion

here is no olden Rule or ommunity uilding Nevertheless use ul rule o thum or implementors m y e to review e h new un tion lity proposed in terms o the five re uirements we h ve identified in this rti le - identity expression uilding persisten e nd sh red interest - nd onsider how it might ontri ute to e h o them

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A Mixed 2D/3D Interface for Music Spatialization

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Abstract. We propose a system for controlling in real time the localisation of sound sources. The system, called MidiSpace, is a real time spatializer of Midi music. We raise the issue of which interface is the most adapted for using MidiSpace. Two interfaces are proposed: a 2D interface for controlling the position of sound sources with a global view of the musical setup, and a 3D/VRML interface for moving the listener's avatar. We report on the design of these interfaces and their respective advantages, and conclude on the need for a mixed interface for spatialization.

Active Listening

We believe that listening environments of the future can be greatly enhanced by integrating relevant models of musical perception into musical listening devices, provided we can develop appropriate software technology to exploit them. This is the basis of the research conducted on "Active listening" at Sony Computer Science Laboratory, Paris. Active Listening refers to the idea that listeners can be given some degree of control on the music they listen to, that give the possibility of proposing different musical perceptions on a piece of music, by opposition to traditional listening, in which the musical media is played passively by some neutral device. The objective is both to increase the musical comfort of listeners, and, when possible, to provide listeners with smoother paths to new music (music they do not know, or do not like). These control parameters create implicitly control spaces in which musical pieces can be listened to in various ways. Active listening is thus related to the notion of *Open Form* in composition [8] but differs by two aspects: 1) we seek to create listening environments for *existing* music repertoires, rather than creating environments for composition or free musical exploration (such as *PatchWork* [11], *OpenMusic* [2], or *CommonMusic* [18]), and 2) we aim at creating environments in which the variations always preserve the original semantics of the music, at least when this semantics can be defined precisely.

The first parameter which comes to mind when thinking about user control on music is the spatialization of sound sources. In this paper we study the implications of giving users the possibility to change dynamically the mixing of sound sources. In te next section, we review previous approaches in computer-controlled sound

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spatialization, and then propose a basic environment for controlling music spatialization, called MidiSpace. We then describe a simple 2D interface for controlling sound sources, and then describe a VRML interface which gives users a more realistic view on the music heard. We compare the two approaches and argue in favor of a mixed solution integrating both interfaces. The last section describes the overall design and implementation of the resulting system.

Music Spatialization

Music spatialization has long been an intensive object of study in computer music research. Most of the work so far has concentrated in building software systems that simulate acoustic environments for existing sound signals. These works are based on results in psychoacoustics that allow to model the perception of sound sources by the human hear using a limited number of perceptive parameters [4]. These models have led to techniques allowing to recreate impression of sound localization using a limited number of loudspeakers. These techniques typically exploit differences of amplitude in sound channels, delays between sound channels to account for interaural distances, and sound filtering techniques such as reverberation to recreate impressions of distance and of spatial volume.

For instance, The *Spatialisateur IRCAM* [10] is a virtual acoustic processor that allows to define the sound scene as a set of perceptive factors such as azimuth, elevation and orientation angles of sound sources relatively to the listener. This processor can adapt itself to any sound reproduction configuration, such as headphones, pairs of loudspeakers, or collections of loudspeaker. Other commercial systems with similar features have recently been introduced on the market, such as Roland *RSS*, the *Spatializer* (Spatializer Audio Labs) which allows to produce a stereo 3D signal from an 8-track input signal controlled by joysticks, or Q-Sound labs's *Q-Sound*, which builds extended stereophonic image using similar techniques. This tendency to propose integrated technology to produce 3D sound is further reflected, for instance, by Microsoft's DirectX API now integrating 3D audio.

These sound spatialization techniques and systems are mostly used for building various virtual reality environments, such as the Cave [5] or *CyberStage* [6], [8]. Recently, sound spatialization has also been included in limited ways in various 3D environments such as *Community Place*'s implementation of VRML [12], ET++ [1], or proprietary, low-cost infrastructures [3].

Based on these works, we are interested in exploiting spatialization capabilities for building richer listening environments. In this paper, we concentrate on the interface issue, i.e. how to give average listeners the possibility of exploiting sound source spatialization in a natural, easy way. We will first describe our basic spatialization system *MidiSpace*, which precisely allows user to control in real time the spatialization of sound sources. Then we describe two interfaces for MidiSpace, and compare their respective advantages.

The Basic MidiSpace System

MidiSpace is a system that gives listeners control on music spatialization. We first outline the characteristics of midi-based spatialization before describing the system.

Midi-Based Spatialization

MidiSpace is a real time player of Midi files which allows users to control in real time the localization of sound sources through a graphical interface (extensions to audio are not discussed in this paper). MidiSpace takes as input arbitrary Midi files [9]. The basic idea in MidiSpace is to represent graphically sound sources in a virtual space, as well as an avatar that represents the listener itself. Through an appropriate editor, the user may either move its avatar around, or move the instruments themselves. The relative position of sound sources and the listener's avatar determine the overall mixing of the music, according to simple geometrical rules illustrated in Fig. 1. The real time mixing of sound sources is realized by sending Midi volume and panoramic messages.

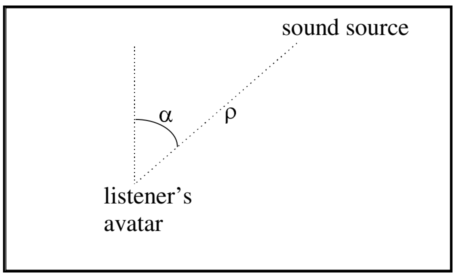

Fig. 1. Volume of sound_source_i = f(distance($\text{graphical-object}_i$, listener_avatar)). f is a function mapping distance to Midi volume (from 0 to 127). Stereo position of sound source i = g(angle($\text{graphical\_Object}_i$, listener_avatar)), where angle is computed relatively to the vertical segment crossing the listener's avatar, and g is a function mapping angles to Midi panoramic positions (0 to 127).

It is important to understand here the role of Midi in this project. On the one hand, there are strong limitations of using Midi for spatialization *per se*. In particular, using Midi panoramic and volume control changes messages for spatializing sounds does not allow to reach the same level of realism than when using other techniques (delays between channels, digital signal processing techniques, etc.), since we exploit only difference in amplitude in sound channels to create spatialization effects. However, this limitation is not important in our context for two reasons : 1) this Midi-based technique still allows to achieve a reasonable impression of sound spatialization which is enough to validate our ideas in user interface and control, and 2) more sophisticated techniques for spatialization can be added in MidiSpace, independently of its architecture.

We will now describe the interfaces for MidiSpace: first, a 2D interface, which provides a global view on the musical setting, and allows to move sound sources around. Then we describe a VRML interface and discuss its relevance for music listening. We conclude on the interest of a mixed approach.

The 2D Interface of MidiSpace

In the 2D interface of MidiSpace, each sound source is represented by a graphical object, as well as the listener's avatar (see Fig. 2.). The user may basically play a midi file (with usual tape recorder-like controls), and move objects around. When an object is moved, the spatializer is called with the new position of the object, and the mixing of sound sources is recomputed accordingly. Other features allow to mute sound sources, or select them as "solo".

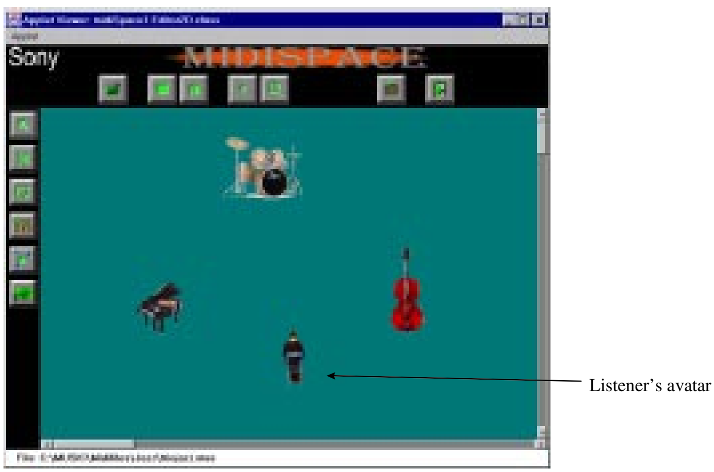

Fig. 2. The 2D Interface of MidiSpace. Here, a tune by Bill Evans (Jazz trio) is being performed

In an initial version, we allowed *both* sound sources and the avatar to be moved. However this was confusing for users. Indeed, moving sound sources amounts to changing the intrinsic mixing of the piece. For instance, moving the piano away will changes the relationship between the piano sound and the rhythmic part. Moving the avatar simply amounts to changing the mixing in global way, but respects the relationships between the sound sources. The effect is quite different since in the second case the structure of the music is modified.

The interface provides a global view on the musical setup, which is very convenient to edit the musical setting. However, there is no impression of musical immersion in the musical piece : the interface is basically a means for editing the piece, not to explore it.

The VRML Interface for Navigating in MidiSpace

Second, we have experimented with interfaces for navigating in the musical space. Several works addressed the issue of navigating in virtual worlds with spatialized sounds. The most spectacular are probably the Cave system [5] or CyberStage [8], in which the user is immersed in a fully-equipped room with surrounding images and sound. Although the resulting systems are usually very realistic, their cost and availability are still prohibitive.

Instead, we chose to experiment with affordable, wide-spread technology. A 3D version of MidiSpace in VRML has been built (see Fig. 3.), in which the VRML code is automatically generated from the 2D interface and the Midi parser. The idea is to create a VRML world in which the user may freely navigate using the standard VRML commands, while listening to the musical piece. Each instrument is represented by a VRML object, and the spatialization is computed from the user current viewpoint. In this interface, the only thing the user can do is move around using standard commands; sound sources cannot be moved.

Fig. 3. MidiSpace/VRML on the Jazz trio, corresponding to the 2D Interface of Fig. 2. On the left, before entering, on the right, inside the club.

Although the result is more exciting and stimulating for users than the 2D interface, it is not yet fully satisfying because the interface gives too little information on the overall configuration of instruments, which is a crucial parameter for spatialization. When the user gets close to an instrument, she loses the sense of her position in the musical set up (e.g. the jazz club, see Fig. 3.). Of course, this problem is a general problem with VRML interfaces, and is not specific to MidiSpace, but in the context of a listening environment, it is particularly important to provide a visualisation which is consistent with the music being played. This consistency is difficult to achieve with a 3D virtual interface on a simple screen.

The Mixed Interface

Based on experiments with users on the two interfaces, we concluded on the interest of combining them for obtaining an optimal satisfaction on user control. The 2D interface is used for *editing* purposes, i.e. moving sound sources. Moving the avatar is not possible in this interface. The VRML interface is used for *exploration*, in a passive mode, to visualize the musical setting in 3D, and move the avatar around. Moving objects is not possible.

The communication between the two interfaces is realized through the VRML/Java communication scheme, and ensures that when the avatar is moved in the VRML interface, the graphical object of the 2D interface is moved accordingly. The overall architecture of MidiSpace is illustrated in Fig. 4.

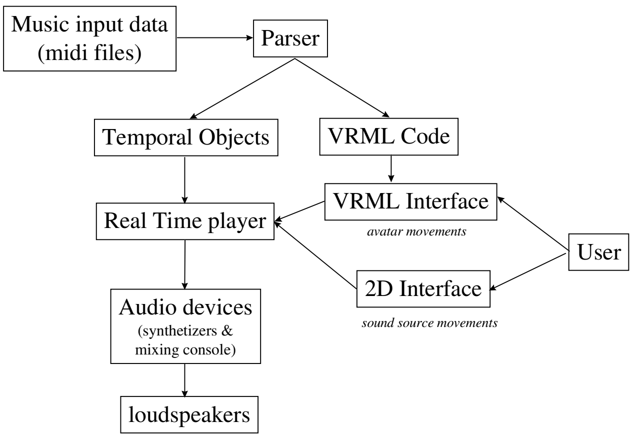

Fig. 4. The architecture of MidiSpace User Interaction.

Implementation

The implementation of the MidiSpace Spatializer consists in 1) translating Midi information into a set of objects within a temporal framework, 2) scheduling these temporal objects using a real time scheduler, 3) the interfaces.

The Parser

The Parser task is to transform the information contained in the Midi file into a unified temporal structure. The temporal framework we use is described in [18], an object-oriented, interval-based representation of temporal objects. In this framework,

each temporal object is represented by a class, which inherits the basic functionalities from a root superclass *TemporalObject*.

One main issue the Parser must address comes from the way Midi files are organized according to the General Midi specifications. Mixing is realized by sending volume and panoramic Midi messages. These messages are global for a given Midi channel. One must therefore ensure that each instrument appears on a distinct Midi channel. In practice, this is not always the case, since Midi tracks can contain events on different channels. The first task is to sort the events and create logical melodies for each instrument. This is realized by analysing program change messages, which assign Midi channels to instruments, thereby segmenting the musical structure. The second task is to create higher level musical structures from the basic musical objects (i.e. notes). The Midi information is organized into notes, grouped in melodies. Each melody contains only the notes for a single instrument. The total piece is represented as a collection of melodies. A dispatch algorithm ensures that, at a given time, only one instrument is playing on a given Midi channel.

Scheduling Temporal Objects

The scheduling of MidiSpace objects uses *MidiShare* [14], a real time Midi operating system, with a Java API. *MidiShare* provides the basic functionality to schedule asynchronously, in real time, Midi events, from Java programs, with 1 millisecond accuracy. More details on the scheduling are given in [7].

MidiSpace Interfaces

The 2D interface uses the standard Java *awt* library, and follows a straightforward object-oriented interface design. The VRML interface is generated automatically from the Parser. More precisely, the Parser generates a file, which contains basically 1) the information on the global setup, 2) description of individual sound sources, corresponding to the various sound tracks identified, and 3) routing expressions to a spatializer object, which is defined as a Java script, using the VRML/Java communication scheme [12]. An excerpt of the VRML code is shown in Fig. 5.

```
WorldInfo {title "Trio jazz"}

# Various global settings
NavigationInfo {speed 2  type  [ "WALK" ]}
# The viewpoint from which the spatialization is computed
DEF USERVIEWPOINT Viewpoint {position -13 0 45}

# The definition of the musical setting (here, a Jazz
Club)
...
```

```
# the Label
Transform {
  translation -2 4.7 21
  children [
    Shape {
      appearance Appearance {
        material Material {
          diffuseColor 1 1 1}}
      geometry Text {
        string "Jazz Club"}}]}


#  The  sound  sources,  as  identified  by  the  Parser  in
General Midi
DEF PIANO Transform {
  children [
    Shape {
      appearance Appearance {
        texture ImageTexture {
          url     "piano.jpg"
          repeatS FALSE
          repeatT FALSE}
        textureTransform TextureTransform {}
      }
      geometry Box {
        size 3 3 3}}]}

DEF DRUMS Transform { …}
DEF BASS Transform {…}


#   The   Java   script   for   handling   movements   and
spatialization
DEF MY_SCRIPT Script {
 url "MusicScript.class"
 field                SFString                midiFileName
"http://intweb.csl.sony.fr/~demo/trio.mid"
 field SFNode channel10 USE DRUMS
 field SFNode channel2 USE BASS
 field SFNode channel3 USE PIANO
 eventIn  SFVec3f    posChanged
 eventIn  SFRotation orientation
```

```
 eventOut SFRotation keepRight
 eventOut SFVec3f    keepPosition}

‟ The routing of VRML messages to the Java script
ROUTE      DETECTOR.position_changed                  TO
MY_SCRIPT.posChanged
ROUTE    MY_SCRIPT.keepPosition                       TO
USERVIEWPOINT.set_position
ROUTE            DETECTOR.orientation_changed         TO
MY_SCRIPT.orientation
ROUTE   MY_SCRIPT.keepRight                           TO
USERVIEWPOINT.set_orientation
```

Fig. 5. The generated VRML code for describing the musical setting from a given midi file

Conclusion, Future Works

The MidiSpace system shows that it is possible to give some degree of freedom to users in sound spatialization, through an intuitive graphical interface. We argue that a unique interface is not appropriate for both moving sound sources and avatars, while giving users a realistic feeling of immersion. In the case of spatialization, although they appear at first to be similar user actions, moving sound sources and moving the avatar bear significantly different semantics, and we concluded that allowing these two operations in the same interface is confusing. We propose an approach combining a standard 2D interface, appropriate for moving sound sources and editing the setup, and a VRML interface appropriate for moving avatars and exploring the musical piece. The prototype built so far validates our approach, and more systematic testing with users is in progress.

Future work remains to be done in three main directions. First we are currently adding a *constraint-based* mechanism for maintaining consistency in sound source positions [15]. This mechanism allows users to navigate in a restricted space, which will always ensure that some mixing properties of the music are satisfied. Second, an audio version of MidiSpace is in progress, to 1) enlarge the repertoire of available music material to virtually all recorded music, and 2) improve the quality of the spatialization, using more advanced techniques such as the ones sketched in the introduction of this paper. Finally, an *annotation* format is currently being designed to represent information on the content of musical piece, to enrich the interaction. These annotations typically represent information on the structure of the piece, its harmonic characteristics, and other kinds of temporal information [17]. These extensions are in progress, and remain compatible with our choice for user interface design proposed here.

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Organizing Information in 3D

l u v ll n n l ögl

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Abstract. s p p r ls r o s sp s o or n z on n sp . on o s p p r s r ro o r xp r n s r n k n o ” n n rs ” M s n ron n or s r n y o n s. n s s on s ss r n ppro s s o or n z n . n s on n l so o s on r r ons r ro o r xp r n s pro r rr n ly ork n on kno n n r ork n l o ”N M s N ”. o l o s pro s o lop ool ox n l s s rs o r r n or on ro orl n o spl y r s l s n r ns ons. sp l pp n n r y q ry n l s s r o n r ly l n r o r s l s n o r r os pro s n s n o r s/ r o n r o r r n or on.

1 Introduction

O g n lly v s s p o n xh on ll s h w ss n (l . p o u knowl g ; pun on ss ns h s n n g m n) n n v s g w n o p o o s own wh n h xh on w s n l n only h v u l p m n . h p o s s p s ML ppl on. h n p s som 100 ML mo ls h soun n omp ny ng x (spo-k n o s ML) onn n o g n z us ng v . h go l o h p o w s o m k h wo k o us n s n s s n s h ms ss l n un s n l o o u n . h sh m ss o m l n h h - og n ous on n h h o n o h nv onm n ll o o g n z on l s u u s h woul llow h us o v h n o m on n o un - s n h onn ons w n h op s. On h o h h n w w on on w h h p o l m o o g n z ng h v ous p s n ons. o solv o h p o l ms h ough -s u u s.

2 Organizational Structures in 3D-Space

n h s p p w s ngu sh n pp o h s o o g n z ng o s n n o m on n h - m ns on l sp . h s pp o h s w on on y h n u o h h h o v su l z (. . g og ph l on p u l

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h u l .) n y h n ss y o m n n oh n n v g on un - on l y n n l ngu g h oughou ll p s o h nv onm n .

2.1 Abstract Structures

h s pp o h m gh us ul wh n m pp ng som sp o h on n (.g. go s su h s n h s o s n) on sp l ng m n o o s. 1 n h s s w s us o llus h ov ll o g n z on. v n h h og n ous on n w hough s o on on h us w h un s mpl s u u wh h oul v n o m on n g n on how h op s w onn .

”Smarties”. n h n y l v l h op s p s n y n o so- ll sm . h y ll h s m s z n l l w h x s ng o ng o h on n . h n no m h s n s l ll h sm s sh h s m olo n u l g y. h olo h ng s o gh y llow wh n sm h s n s l n o wh n h us m g s om h op (n logous o v s l nk h sm om s v s sm). n h s w y h us n k p k o h s pos on n h s mov m n s. h sh p o h sm s w s on on y h sks h y h o p o m n h ov v w w s mpo n o h v n o h woul v y s mpl n o o wo k n los up s w ll s om s n . hos o g v h o s n o n on . . on on w s mo p om n n h n h o h s s n h o n on o h sm s p ov h v su l lu o wh h w s h m n pl n . h n y l v l n s ly xp n o mo y ng o su ng sm s n o o ommo n w op s o h ng s n on n .

Spatial Arrangement. n ll h op s spl y n h ov v w g v n qu l mpo n n h s no p ul o n wh h h y h v o xplo w o o us on h l onsh p w n h op s. hus ll sm s loos ly g oup y go y .g. ll sm s on n ng wo l s h l w h ology ng n lus . Mos op s .g. h gh- n gy phys s l w h num o n on p s n pp o h s n h o spl n o su -wo l s. l k ng on y llow . . s l sm s h on n su - op s spl ys su s u u m om p l y llow sm s onn y h s xpl n ng h onn on w n h su - op s (lso g. 1). h n o u on o xp n l su s u u s lso h lp o vo lu ng h n y l v l w h oo m ny o s. h us n hoos h sm s y po n ng n l k ng h m h s l op om s h n o h wo l p om n n ly pl n h m l o h s n. ll h o h sm s now g oup oun h s po n hus sm s pl n o h n l on on n op s l o wh l hos h w y o v ously l w h ssu s h only mo ly onn o no l ll. h us n o oun h s n w n y us ng h ows h g s o h - m (lso g. 1). p l soun w s us o nh n h o n on.

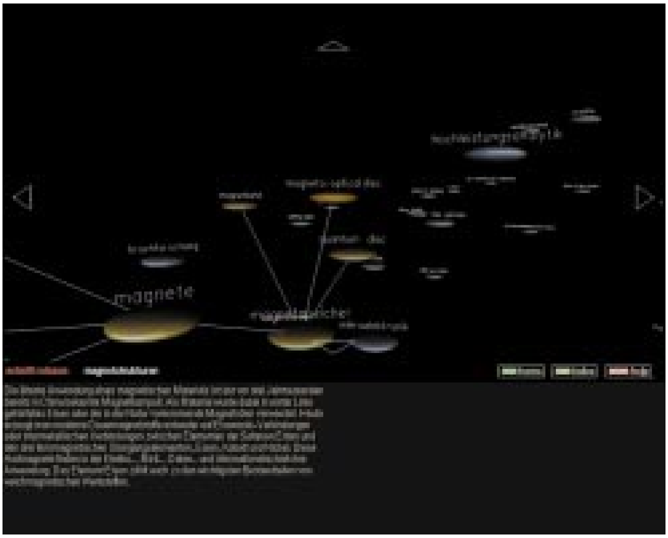

Fig. 1. h n y l v l o h nv onm n show ng *labeled smarties substructures* n *arrows for navigation.*

Conclusion. h s up s n h p v ous s ons wo ks w ll o x- pl n ng h l ons w n h op s v ly onv ys s ns o h sp l ng m n o h o s n h o ou h l on o h o h . u n ou o g un o p opl who us w n o xplo h nv onm n w hou look ng o ny h ng n p ul n h lp p opl k p k o v s un xplo s. On h o h h n u n ou o h um som o p opl look ng o sp op s o g n z ng h sm - s sp lly n l l ng h m s no nough o sy v l. h s w s wo s n y h h w s h h o n su l s z o w n o n x h h x woul pp mu h oo l g wh n h o w s los o woul ly l wh n v w om s n h llow ll o s o s n. v l pp o h s n hough o

l ng h s z o h x o ng o h v wpo n h ng s n s n . h s op on w s opp s n h w s h w l ng.

l ng h s z o h x o ng o h v wpo n h ng s n s n . h s op on w s opp s n h w s h so n ng.

pl ng h n y l v l s u u w h sup s u u wh h sm - pl s g oup o sm s om h o g n l on gu on. h s solu on w s s s n woul k h us on mo p v s p o h h mo ls.

pl ng h sm s w h ons woul s ll qu l l ng s n h y llow o o ng o n p on.

2.2 Organizational Structures Resembling the Real World.

M ny op s s o g sp wh n h us s on on w h p s n- on o h l h ng no us s p on o llus on. o n n v s h s w s u o op s h l w h sp l ng m n s o som k n .g. h olog l s s g og ph l h sol sys m o op s h nvolv p o ss s .g. xp m n s n qu n um phys s o p o u on s ps u ng mol ul m p xy. O g n z ng h n ss y n o m on o h s op s h ough mo ls n -sp us m n u l n wo k ly w ll.

Models as Organizational Structures. n som s s mos o h n o m - on o ommun s nh n n no su h s u l ng o m h n . h x mpl w s uss h l w h h x v ons o h ngh us n ph sus p o y h us n h olog l ns u n h us n my o n s. h mo l p s n s p l ons u on o h u ns o om n p m n .

Fig. 2. h mo l o h om n p m n n ph sus show ng h *labels* us o n v g on n n o m on v l.

Navigation. h l w s sy o onn h n om on o h o s w s no so sy o ommun o h v s o wh h o s o us . h s p o l m w s no on n o h ph sus mo l h w s o m k h o s s n ou l ly wh l on h o h h n vo ng h h m k o s woul n w h h mosph n ov ll mp ss on o h mo l. Mo g n - lly sp k ng w s mpo n o n n v g on n v l m ho h oul p o h v ous s u ons n lso o h n y l v l. xp - m n w h p n ng l k l o s p ul olo n pp o h h soon p ov o h v m ny w ks sm ll o s w no s ngu sh l nough un m l o s su h s p s o m h n s o v s n on l n o - m on on h pu pos . su lly h olo ng lso h s h s o h

mo l. no h pp o h ons s n no m k ng h o s n ly ng on h u so o h ng om n ow o h sym ol o h n . h s p ov h ous s n v n w h h s mpl s o s nvolv us ng ls. n lly s l o wh l ls s gn ng l k l o s n k o l k l ls h s v s xpl n o y no s only. L l ng h lp xpl n n o n h o h lp h v s o wh h sh h w n o know mo ou . o s llo n h low gh o n o h ML m s v s l nks o on p s n l op s no h o n o . o xplo h hous h us l ks on h v ous l ls m k ng pl s o n s y o ng so h sh mov s h ough h ooms n s p s n w h kg oun n o m - on. h s qu n o l ls lso gul s h o n wh h h mo l n xplo .

2.3 Merging Both Systems

o som op s s m goo o om n l s mo ls w h n s s u u . us h sm s s n h us w s l y m l w h h m om h n y l v l n ogn z h m s x n ous l m n s pl n h mo l o o n on n n o m on v l.

The "Smarties" as Markers. h l o m gh s v s n x m- pl wh sm s w us o m k s n v lo ons n mo l. n h l o w s p s n s h m lly h sm s oul us s m k s h ll o n on wh l w s suffi n ly l h h y no o spon o l o s.

Fig. 3. h l o show ng *"smarties" used as markers*

The "Smarties" as Carriers of Content. s on p s h no s ly v su l z m gh s o un s n y us ng -s u u s o o g - n z ng n o m on. o h s on u on p o h h gh- n gy phys s s on

s m s o us n s p s n on o h v n s k ng pl n h s mom n s h un v s s o x s . g n h sm s w mploy s m k s h s m on m -s l . s soon s h y l k h y sp ll h on n llus ng h p l s n o s x s ng h v ous s g s o v lopm n .

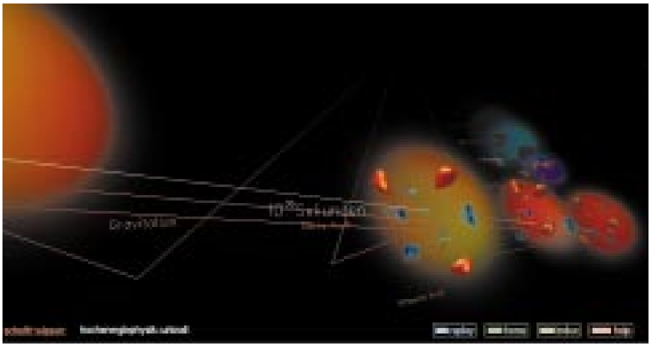

Fig. 4. h g ng mo l show ng *"smarties" used as carriers of content*

3 Future Directions

3.1 Towards a New Information Architecture

h p o ss o m pp ng x s ng on n n -sp g v s ss o onn ons n sp s h h p v ously n n gl o w us no v s l . h p - ns ogn z l n sp l ng m n o h ngs llow h us o ns n v ly g sp onn ons n su s qu n ly o us on h mos n s ng o p om s ng spo s.

3.2 Conclusion

o n v u som s w ons mpo n o u u v lop- m n .

Data Driven Structures. h o g n z on l s u u s w mploy n n n v s w mos ly us om lo o h sk h n . h m p- p ng o h on n on o -s u u s w s no u om . . h p h o m nu lly pos on l l n n ow w h sp un on l y. o som sks .g. h s u ons s n s on . n . h s p- p o h wo ks w ll n s h o h nk o su s u m ho . o s s u u s s s n s on .1 mo v n pp o h .g. h

u om z on o h on n m pp ng o ng o p n s o ul s llows o h s gn o mo fl x l nv onm n s. n m s un h qu y s su m y hoos ng on p s om - p s n on o h un ly ng on ology wh l h v o um n s spl y s o s n sp l sys m.

Improved Navigation and Orientation m gh h v h ough s gn l m n s su h s y n o u ng l n m ks o o n on o y ng g o v lu s n s o y o ng p n l v ws su h s ov v ws o pl ns h l h us h k h s h pos on n sp n h ov ll ng m n o h o s. n h s on x l v ls o p s n on h llow h us o sw h om v y l v ws o ov v ws o h nv onm n n mpo n ssu .

Alternative Ways for Representing Information, . . sw h ng w n n p s n ons o h on n o ng o n n ss s. On h o h h n h nv onm n m gh pp n o ng o n us s ss s us o h s h p n s .g. h us m y us om z n nv onm n o n ss o v w n p s o .

Allowing for a Wider Range of Interactions . . g v ng h us h pos- s l y o ng h nv onm n o o p son l nv onm n . h us m gh lso g v n h p l y o h ng h pp n o h o s l v s n h nv onm n pos m ss g s ommun w h o h us s .

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Human Centered Virtual Interactive Image World for Image Retrieval

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Abstract. n h s p p r h mpl m n on o r l worl wh h s s or m r r l s s r . h s r l worl s ll o n wh h ons s s o l r n m r o m s o r r . h s s o n h s 00 m s o flow rs r sh p n n s n p n s fin r s. o n shows m s o h m n n h n s s onfi r on r n h n r ons w h h m n who w sh s o xplor n fin m s n h worl . h n shown h worl h n r o h worl s lw ys k y m wh h s s l y h m n so h s s h m n n r worl . h worl h s r ons s h s olor r ons n r onfi r s l s h n r o h worl h n s. h worl n show m s o h m n y n m on n o rs oo m n x n ool. r m k n s h worl o r l z h worl wh h r spon s o o r own m n n h pro ss o h n r on or s r h n som h n . r n h s p p r h pro ss o s r h n m s s s r s on o h ppl ons o xplor n h r l worl . h mos or n l h r s h h worl h n s s onfi r on n or n w h h ry n r ons w h h m n so h h o l fin wh h w n s q kly n mor o r h wo l n o n r w h som h n wh h h o s no known n n . s h ry h r r s s o r l worl n omp r m mory o h n s onfi r on s ly.

Keywords:

r r s z on n r s r n n r on n n r wor r r on r on sp o n or on K os op on on o wor n wor n x n .

1 Introduction

r n r wor w n s s on r on r n n r ons w n w o w s s o xp or wor n so n ro wor . r son w w r n s wor s o r z wor w r spon s o o r own n n pro ss o n r on or s r n

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so n n w n n n w w n s q n s .
r n s p p r pro ss o s r n s s s r s on o
pp ons o xp or n r wor . os or n n s p p r
s wor n s s on r on n or n w r n r
ons w n so o n w w n s q n or o r
wo n o n r w so n w o s no now n n . s
r r r s s o r wor s n o p r or o n s
on r on s . n r wor w on on wor on
w n s n r wor s s w w s w r fl o r n n
s own n pro ss o n r ons w wor . r now n s
r wor n w s wor s o n .
n o ow n s ons o n w s r . n s on n
r r s s w s s o o n w n ro .
n s on w xp n o n s n n r wor . n s on
r on n o n w xp n . n s on r on r on o
o n n n r on w s ss . n s on 6 n on o
o n w s own. n s on 7 ow r pos on n o n
w s o n x s w xp n .

2 Image Retrieval as an Application of Moving-VW

op r r s n pp on o o n . n o n
s pp o r r s n r o n o n s
n o s s n z p n n s n p n o s
p n n s o n s o p r pro r n . s o
r r n s p p r s r r s s r n
w n s so s r w s or s r . s s
r rns s r r s n s r or r o . s r
or r n n r o s. n s o or s s s
pp o r pr s n s r o ons n n or r
o r n ons n n or r o ons n n s or
on o s r . n s o or s s s pp n or
r o s r on n or r o n ns n s or on o
s r . n wor o s or on o s r
wor s r n x o s. K wor s r n n
w s r s n o o n r r s s n wsp p r r r
p n r r n so on. r r s r wor s n o o n
r r w s ows r r r s s n wo ns ons sp 1
or n r ns ons sp 6 . r r w wor s w s ows
r r r s o s n r ns ons sp .

3 Human Centered World

o n s n n r wor o n p s s ns n n o
s ns . s s r s w s o n r o o n .

Lo r r r s s n n r o s s s own n s r or r ro . o w s s s r s w s n r o o n . r 1 s ows s r o n r o o n .

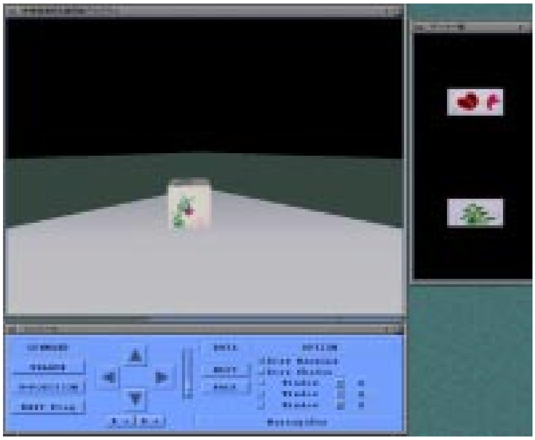

Fig. 1. r n r o o n .

4 Direction in the World

n w w r os n n w r on s o w ? Loo n or n r n n r n r o s s s s on o n os n n . r w w r ons ro w r o s r ons ¿ ro w w r w n o s or oo s o s. o r r w s r ons o . o n s ows r ons or s r. r ons w w r p n n o n s s r s s r o ons n o r r n s r on n n ns . O o rs r r n o r r ons w w n n o . r s n wor r on s r r on on p r on n so on. p n on n on o o s r ons r n x r s r or s. r s ows r s o r r s own n r on w n wor . n r p n s o o o n r r n n n o o or s s n s r o n s r or r o w s o n n r p n.

5 World Reconfiguration by Human Interaction

s r n s n w s r ro pr o s s r r s . . ro pr o s r wor . n n n x s r w

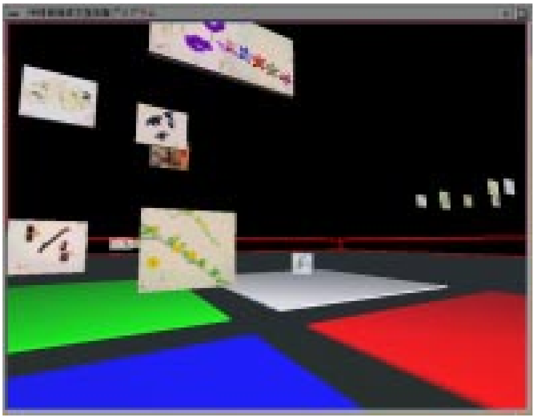

Fig. 2. r s o r r s own n r on w .

s n s s r . s r s n w s r r s w sp n o r wor s n w wor w s r n s s own now on sp w r ons. r s ows s on o n w s r or n x r r . o o w os r w s p s z s s n w s r . s n w s r w s o n r o wor s .

s pro ss s w w r on r on o wor n n r on. s n w s r s o n r o wor n n w s r r s w s sp . n r r n s w r p r rs s r n n n n r n s r rs s r s r o n r wor w s s n n s or . s s o n o n r n nown wor w s. s r n r r wor s s s w r oo n n o os op w o s x o n n w wor .

6 Animated World

n wor s r n r o s s o sp o s on s r n on . or s s s r n n rn so s r n s w . r s ows n on o s or s own n r r r s o s r. r n n on s r n s w s n on s r n.

On n rn s s r s s r n oo or w w n s o r r s o s r r s . r n w s r n r s s r n n n w n ows w s n ro . o s o s n on o s r ss ro s r o s s n r s n r s o o r s . on o s o n w n ow s now n pro r ss.

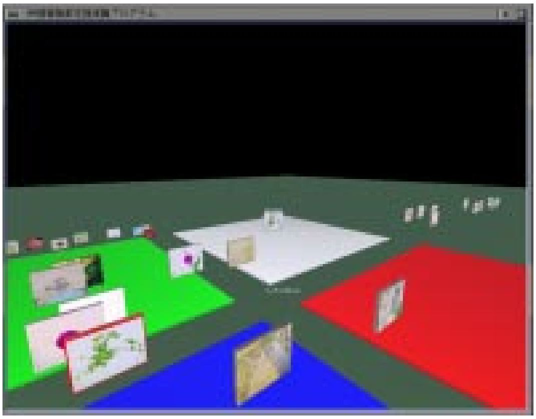

Fig. 3. on o n x s r .

r s ows o ws n w o pro ss o s r . wor s op o r n s s r op n n s w s r s o r n r n r o o o r .

7 Relative Indexing of Images in the Image World

n o n or on r r o n s s s n wsp p r r s n p p rs n oo s r n x wor s or n r o r rs. on ro r n x n s n s r s s on o w s s w o n x n . O r n x n o s r r r n x n n n r n x n . or z on o o n s n n x n r so s or n x n o n s.

On o r n n o r r s r r r on n s s s o or or o s w s n s s. o ors n o s r p s r s o s. s o r o n z o s n s o p rs. wor s w r pr s n on p s o s w r n x s s or r r n s.

propos o o n x n s wor s. s o s r n x n . s o ss s r r so s w r r n x wor s. s s s own n r 6 s w r r n x r o so orn rs o sp r n n w s o n o n x s o n r o sp r n nn n . s r n o o n x n r o s w n s r n r o o n x n so s ns s s o s r os or os o on n s o s r s . n o n x s s wor s ro n r s w w s n

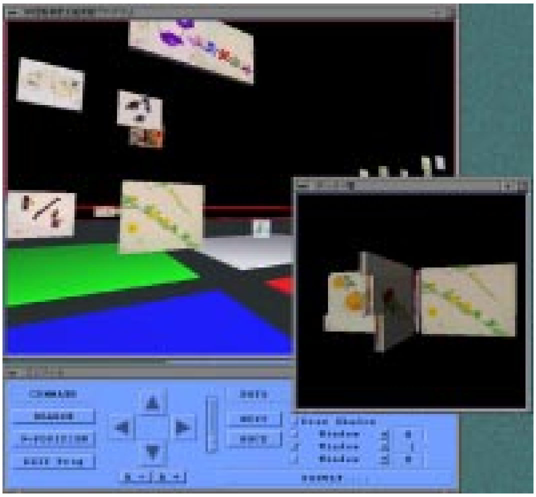

Fig. 4. n on o s.

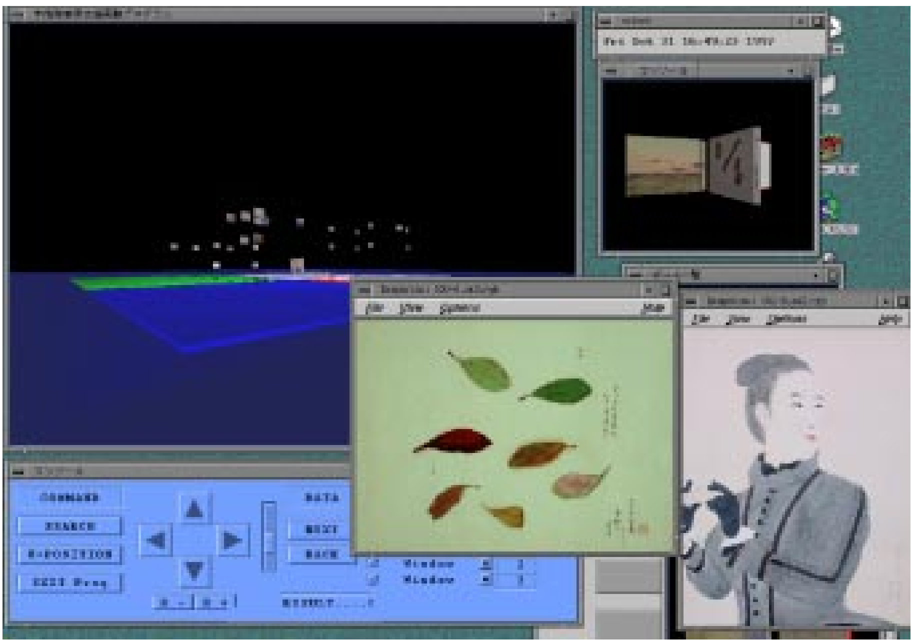

Fig. 5. o ws o o n .

propor on o s n s ro n r s. s wor s n r w s n n n or o p on.

p n r n x n n n xp r n . o p r wor s n x r n x n n wor s n x n . r s o xp r n s ows 70 n n n x n n n r n x n . r s n xp r n r s w s ows on wor s w w r n x o s r n wo p rsons 70 s n r s s n n x n .

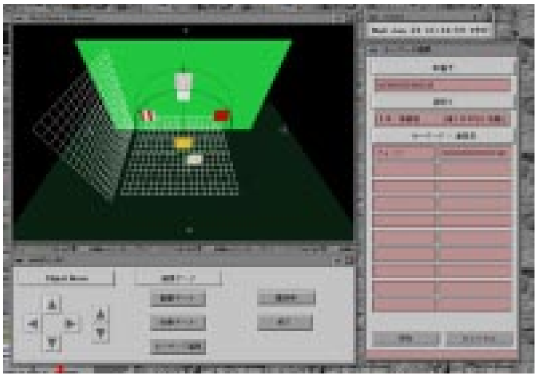

Fig. 6. n x n n wor .

8 Summary and Future Works

o n w s s r . o n s n n r wor w os on n s o ono s s s flow rs r s p n n s n p n s n r s. wor s r ons n n r on r s s s n r o wor s n n. o wor orr spon s o n. wor n n s n or r o oo w o s. n so n or r o n x s o rs oo w s z s r r ons o s. s n x n o s r n x n .

o n s s p n n s n now. o xp r n s s ow r n x n s s pr s s n n x n .

O r r wor s w n n o w o wor n r s o wor r n w po n s w s n n w p rsp s o wor n s p r pos n o o n s o o s n s on sp or n n r ws.

r o K mo o

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. . ll mson n . hn rm n h yn m om n r l n y n m q r s n r l s n orm on xplor on sys m n ro n s o h nn l n rn on l on r n on r s r h n lopm n n n orm on r r l p s 1 .
. . l s n yn m q r s n s l n orm on s k n n r s n ro n s o h n rn on l sympos m " n o h ' " p s 1 .
. . K mo o h n r m l r on l n orm on spl y n sys m n ro n s o n n rn on l workshop sponsor n or n z y h spr work n ro p " " o ly p s 7 1 .
. . mm . K nk l . ll Ly r orl s l z on s r n r s ppor n ll x r r l n ro n s o h nn l n rn on l on r n on r s r h n lopm n n n orm on r r l p s 1 .
. . o . . rs n . . rs . . k nl y .K. r L. s n r . l ors n n . . o r son h n r on n h l l r ry omm n ons o h ol. o. p s 1 .

Virtual Great Barrier Reef: A Theoretical Approach Towards an Evolving, Interactive VR Environment Using a Distributed DOME and CAVE System

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Abstract. The Australian Great Barrier Reef is a natural wonder of our world and a registered UNESCO World Heritage site hosting 1.5 million visitor-days in 1994/95. Tourism is currently the main commercial use and is estimated to generate over $1 billion annually.[1] With the coming 2000 Olympics in Australia, tourism increases will substantially present a major conservation and preservation problem to the reef. This paper proposes a solution to this problem through establishing a virtual reality installation that is interactive and evolving, enabling many visitors to discover the reef through high quality immersive entertainment. This paper considers the technical implications required for a system based in Complexity: a distributed DOME and CAVE architectural system; a mixed reality environment; artificial life; multi-user interactivity; and hardware interfaces.

1 Introduction

"Well, life emerged in the oceans," he adds, "so there you are at the edge [diving off the continental shelf], alive and appreciating that enormous fluid nursery. And that's why the 'edge of chaos' carries for me a very similar feeling: because I believe life also originated at the edge of chaos. So here we are at the edge, alive and appreciating the fact that physics itself should yield up such a nursery..."

- Chris Langton, artificial life pioneer, commenting on Complexity.[1]

[1] Waldrop, M. Mitchell, 1992 Complexity, The Emerging Science at the Edge of Order and Chaos, page 231. Simon & Schuster, 1992.

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1.1 A Cinematic Narrative Virtual Walkthrough

Jack, Jill and Tanaka have entered the Virtual Barrier Reef Exhibition, where "Nintendo" meets classroom. Before going into the environment, they have to choose from several different experiential options: Jack picks the "Marine Biologist," Jill picks the "Dolphin" and Tanaka the "Snorkeler."

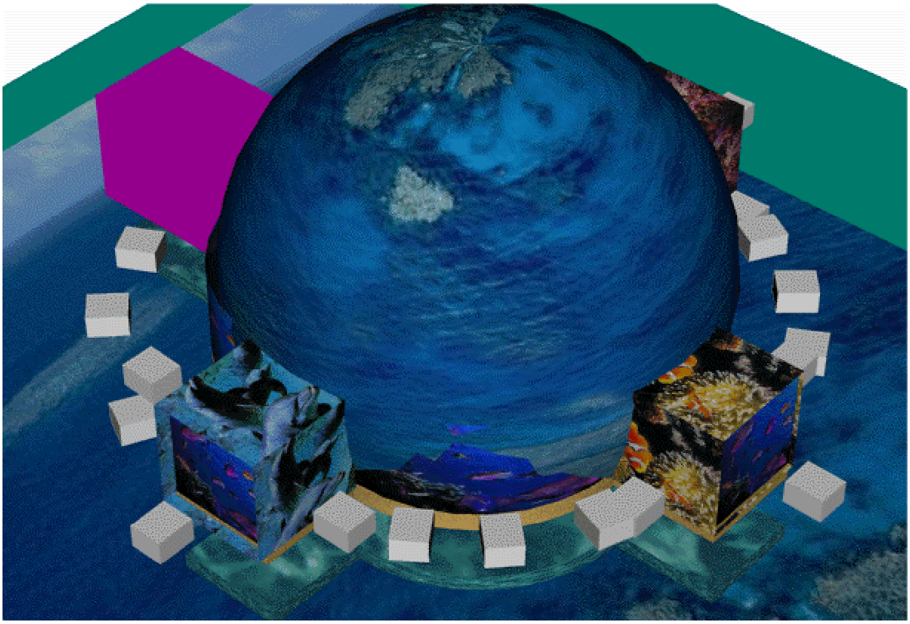

Fig. 1. Overview of the Virtual Great Barrier Reef installation consisting of a 15 meter diameter DOME, Interactive WALLs, 3 CAVE systems and a motion simulator.

When they put on their equipment mainly consisting of 3D shutter glasses, audio communication and other interactive devices, they enter the Dive Vehicle (motion simulator) that takes them on a small "journey" to the reef. The Immersion hatch opens and they exit into the main DOME [Fig. 1] finding themselves immersed in 20 meters (60 feet) of water. The main DOME [2] (15 m diameter x 15m high, 360° x 180°), enables them to see fish and other species swim about in 3D. They see a mix of autonomous fish, avatars and avatar guides that assist, guide and role-play. They hear soundscapes of the reef. They can also see 3 CAVEs [3]. They were told that the installation was directly linked to the real reef to affect the climatic conditions within the installation. The installation's environment was persistent, evolving and adapting just like the real reef.

Jack finds a school of fish that holds his interest, and points to it using the "laser and" pointer on top of his Dive Panel. The panel displays the information about the fish, life habits, predators, eating, mating habits, etc. Then, a big grouper swims to him (guide avatar) and engages him in a conversation about the reef. A dolphin joins

in and he finds out its Jill, and they are able to communicate together through the group communication channel with their headsets.

Tanaka finds an autonomous fish guide and several descriptor icons floating nearby. He selects the Japanese version. He inserts his smart card in the nearby stand, then experiments with the inter-related lives of the species inhabiting that community by moving the various avatars around with a Fish data Glove. At one point a mythical aboriginal character swims by and heads for one of the CAVEs. At the warning beep on each of their timers, Jill and Tanaka to return to the visitor's center. Jack extends his visit by buying more air directly through his smart card and Dive Panel. Once in the visitors' center, Jill and Tanaka insert their smart cards to get a color print out of their activities during their visit.

1.2 The Complex Architecture

The system is a large distributed network based upon proven, stable DOME and CAVE technologies. Similar reference models in which this project is based upon can be found in the past projects of NICE [4] and ROBOTIX: MARS MISSION [5].

The NICE project is a collaborative CAVE-based environment where 6 to 8 year old children, represented as avatars, collaboratively tend a persistent virtual garden. This highly graphical, immersive virtual space has primarily been designed for use in the CAVE, a multi-person, room-sized virtual reality system. As the CAVE supports multiple simultaneous physical users, a number of children can participate in the learning activities at the same time.

Interactive DOME projects including the Carnegie Science Center's "ROBOTIX: MARS MISSION, was the first example of Interactive Virtual Reality Cinema. Each audience member had a three button mouse device that allowed them to make group decisions on story and piloting spacecraft. The graphics were rendered in real-time, called from an extensive database of Mars's terrain from NASA. The partial dome sat 35 people, and was 200 degrees wide and 60 degrees high. The system used a SGI ONYX, with 4 R10000 processors, Infinite Reality Engine, Audio Serial Option board, and display boards. The polling system, custom built, fed into a PC which talked to the SGI. Majority vote ruled. The dome display used 3 state of the art Electrohome RGB projectors. Most important, only one graphic pipeline was used, and split into three views using custom built software and edge blending. The overlap on edges was 25%, and it appeared seamless and no distortion. Performance, 30-90+ fps, no lag. Audio was 3-D spatialized, custom built software, with floor shakers. It ran for 9 months, no glitches. Effective, there were some people who *thought* they went to Mars.

1.3 Methodology of Application

Whilst the true objective of this installation is to install a strong sense of conservation and preservation to the future visitors of the Great Barrier Reef, it seeks to apply it through a Constructionist [6] and "Immersive role-play" educative model steeped heavy in "Nintendo" style interaction of total consciousness submersion. Thus, our methodology objectives are simple – give the visitor an experience that they

constructed for themselves, immerse them in wonder and inspiration, give them a reason to care, in their minds really take them there, and finally, afterwards give them something material they can use to prove and remember their experience.

2 Distributed DOME and CAVE Architectural System

2.1 The DOME Zone

The DOME zone is constructed of CG and real-time/pre-captured video which is projected onto the scrim of the DOME together in layers to assist with overall processing quality of CG and simulations. The background is a mix of live or pre-recorded scenes in the reef, and the CG fish are projected bright enough over the top of it to create the mixed illusion. Of course there will have to be certain areas, such as coral and other big blocks of CG that have to be animated, but these aren't that computationally intensive as they update on a slightly slower level.

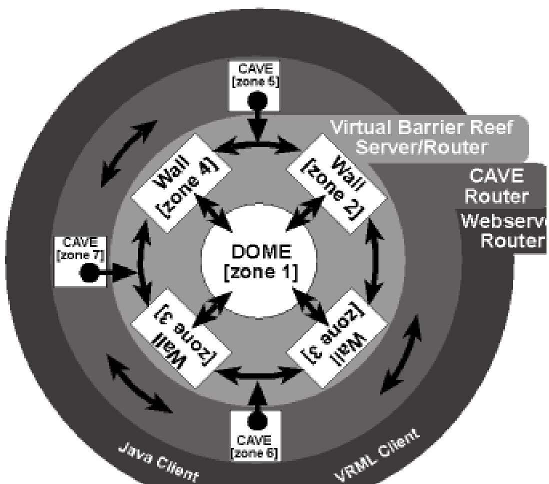

Fig. 2. Distributed Relationship of the DOME, CAVES, WALLs and the Internet.

2.2 Multiplexing and Mixed Topologies

Since the DOME is the central "Hub" [Fig. 2] of the environment physically, and holds the most connectivity to all other zones, we will use it as the focus to consider the many facets of multiplexing within the environment and the various other network topologies and protocols that connect to it.

2.3 The WALL Zones (4 WALLs)

The walls will be the most computational expensive of all the zones in the environment as most of the direct interactivity will happen around them. Walls are interactive in that they might have species that will react when visitors walk by them. Example would be an alife moray eel might come out to feed, and when a visitor walks up to it quickly, a sensing device gives it spatial reaction information. Spot projectors and smaller independent computer systems are displaying various small interactive displays, while the meta environment was separate and being processed by the SGI system.

2.4 CAVE Zones: (3 CAVEs)

CAVEs are separate zones or environments that are story related. They can host indigenous or mythical stories related to the reef and its inhabitants. Here the visitors can have a more immersive, intimate experience with the denizens of the reef, as the sea creatures swim and interact with the visitors within the 3 meter cube of each CAVE.

The CAVEs use the standard network topologies and protocols being developed as part of the CAVERN network [7] to deal with the multiple information flows maintaining the virtual environments.

Each of the CAVEs, WALLs, and the DOME making up the environment will be connected via a high-speed network, allowing information such as avatar data, virtual world state / meta data and persistent evolutional data to pass between them. This will allow avatars in the CAVEs to swim over onto the WALLS or the DOME, and allow museum guides in the guise of reef inhabitants to interact with the visitors. This will also allow remotely located CAVE users in the United States, Europe, and Asia to join into the collaboration. Similar connectivity has been used in the NICE environment [8] to link multiple CAVE sites in the United States to Europe and Japan.

3 Mixed Reality Environment

The environment of this project uses video, lighting, and sound techniques to establish an environment that convinces the user that they are indeed immersed in the Great Barrier Reef.

Video: Video will be used in strategic places includes some parts of the walls and the floor. The main imaging of the floor is video, with spot CG projections to provide a better illusion of immersion and non-repetition.

Sound: immersive and 3D in its localization, the sound system provides authentic sounds from autonomous life and "extra spatial" depth sounds.

3.1 Real-Time Connectivity to the Reef

Climatic Interference: The virtual model is connected real-time to a section of the real reef so that it can automatically adjust the virtual model. Temperature, current, air pressure and other climatic conditions on the reef will cause several actions in the virtual environment, such as temperature of the room, flow of the virtual debris, virtual water currents, etc.

3.2 Complex and Evolving Environment

This environment is considered to be a "living entity", possessing an authentic as possible simulation to the real reef.

For simulating simple fluid flow, we consider techniques similar to the ones used by Wejchert and Haumann Wejchert 91 [9] [Fig. 3] for animating aerodynamics.

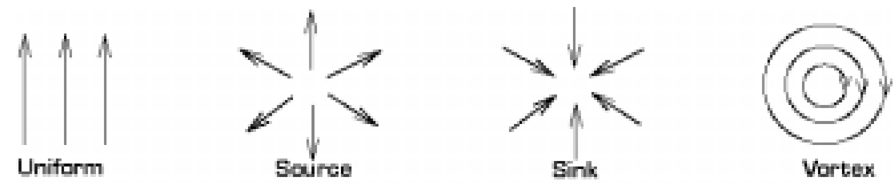

Fig. 3. The flow primitives (reproduced from the paper by Wejchert and Haumann)

Assuming inviscid and irrotational fluid, we can construct a model of a non-turbulent flow field with low computational cost using a set of *flow primitives.* These include *uniform flow* where the fluid velocity follow straight lines; *source flow*--a point from which fluid moves out from all directions; *sink flow* which is opposite to the source flow; and *vortex flow* where fluid moves around in concentric circles. This process is also directly linked with the real reef current flow that is constantly supplying real-time information. Both of the processes integrated together enable lower computation requirements and increase the authenticity of the virtual environment.

Much of the seaweed, plankton, coral and other movable plant/marine life are simulated and respond dynamically to water currents and movements of other life in a realistic manner. In this case it is proposed to use a system which builds the plants in a mass-spring chain assembly. In order to obtain computational efficiency, we do not calculate the forces acting on the geometric surface of each plant leaf, rather, we approximate the hydrodynamic force at each mass point.

4 Artificial Life

The artificial life treatment in this project is an exciting and innovative one. As mentioned earlier, one of the educative goals in this project is to enable people to

"think like a fish" so they can experience first hand through the "eyes of a fish" what it's like to live on the reef.

To achieve this, we have developed two types of models for Alife. The first model is a totally autonomous animal that behaves according to the events in the environment. It has a life span, is integrated into the ecological system, and possesses authentic behaviors of its real life counterpart.

The second model is a similar model, only that the "brain and motor skills" are detached and placed into the control of a visitor using a dataglove to direct the fish. The innovation here is that even though a visitor is controlling the "will and motor" of the artificial fish, it still has behavior and characteristic traits that will not allow you to act outside of the character set for that fish.

4.1 Artificial Animals for Life-Like Interactive Virtual Reef Creatures

What's the key to bringing you a captivating experience as a tourist of the virtual Great Barrier Reef? Whether you are merely observing the schools of sardines, playful dolphins and vicious sharks, or you are living the aquatic life by playing the role of one of the virtual reef dwellers (want to be a dolphin, parrot fish or maybe a reef shark? Sure you can), realism is the password to the ultimate immersive experience. Here we are not just talking about visual authenticity in the appearance of the digital sea creatures, but also in their physical environment, and most importantly, in the way they move, perceive and behave. In an interactive environment like ours, behavioral realism, especially, autonomy of the virtual creatures is indispensable.

How are we to achieve such integrated realism? Our answer is to build Artificial Life (or Alife) models of the aquatic animals. The properties and internal control mechanisms of these artificial animals should be qualitatively similar to those of their natural counterparts. Specifically, we construct animal-like autonomy into traditional graphical models by integrating control structures for locomotion, perception and action. As a result, the artificial fishes and mammals have 'eyes' and other sensors to actively perceive their dynamic environments; they have 'brains' to interpret their perception and govern their actions. Just like real animals, they autonomously make decisions about what to do and how to do in everyday aquatic life, be it dramatic or mundane. This approach has been successfully demonstrated by the lifelike virtual undersea world developed in [10, 11].

We tackle the complexity of the artificial life model by decomposing it into three sub-models:

- *A graphical display model* that uses geometry and texture to capture the form and appearance of any specific species of sea animal.
- *A bio-mechanical model* that captures the physical and anatomical structure of the animal's body, including its muscle actuators, and simulates its deformation and dynamics.
- *A brain model* that is responsible for motor, perception and behavior control of the animal.

As an example of such an artificial life model, [Fig.4] shows a functional overview of the artificial fish that was implemented in [10, 11]. As the figure illustrates, the body of the fish harbors its brain. The brain itself consists of three control centers: the motor center, the perception center, and the behavior center. These centers are part of

the motor, perception, and behavior control systems of the artificial fish. The function of each of these systems will be previewed next.

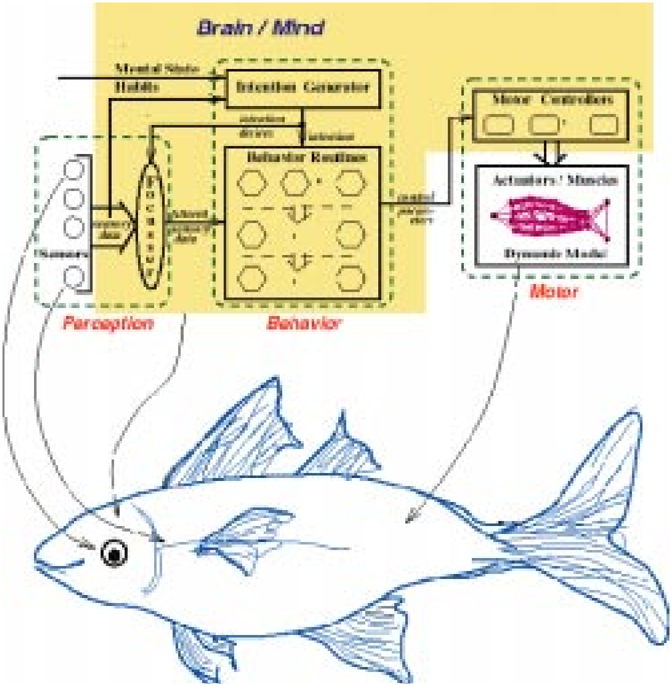

Fig. 4. Diagram of an autonomous and avatar model fish

4.2 Motor System

The motor system comprises the dynamic model of the sea creature, the actuators, and a set of motor controllers (MCs) which constitutes the motor control center in the artificial animal's brain. Since our goal is to animate an animal realistically and at reasonable computational cost, we seek to design a mechanical model that represents a good compromise between anatomical consistency, hence realism, and computational efficiency. The dynamic fish model [12, 13] represents a good example. It is important to realize that adequate model fidelity allows us to build motor controllers by gleaning information from bio-mechanical literature of the animal [14, 15] Motor controllers are parameterized procedures, each of which is dedicated to carrying out a specific motor function, such as ``swim forward", ``turn left" or ``ascend". They translate natural control parameters such as the forward speed, angle of the turn or angle of ascent into detailed muscle or fin/leg actions. Abstracting locomotion control into parameterized procedures enables behavior control to operate on the level of motor skills, rather than that of tedious individual muscle/limb movements. The repertoire of motor skills forms the foundation of the artificial animal's functionality.

Given that our application is in interactive VR systems, locomotion control and simulation must be executed at interactive speed. Physics-based dynamic models of animals offer physical realism but require numerical integration. This can be expensive when the models are complex.

There are various ways to speed things up. One way is to have multiple models of increasing complexity for each species of animal. For example, the simplest model will just be a particle with mass, velocity and acceleration (which still exhibits basic physical properties and hence can automatically react to external forces, such as water current, in a realistic manner). The speed-up can then be achieved by way of `motion culling', where when the animal is not visible or is far away, only the simplest model is used and the full mechanical model is used only when the animal is near by. This method, however, is view-dependent and can be tricky when the number of users is large. Another way is to use bio-mechanical models whenever possible (when they are simple enough to run the simulation at real time) and with more complex animals, we can build pre-processed, parameterized motion libraries (which can be played back in real time), like what is used by most of today's games. These (canned) motion libraries can be built from off-line simulations of elaborate bio-mechanical models of the animal or from motion-captured data. One thing to keep in mind is that, no matter what the underlying locomotion model is, its interface to the behavior system should be kept comparable as parameterized procedures of motor skills.

4.3 Perception System

Perception modeling is concerned with:

1. Simulating the physical and optical abilities and limitations of the animal's perception.
2. Interpreting sensory data by simulating the results of perceptual information processing within the brain of the animal.

When modeling perception for the purposes of interactive entertainment, our first task is to model the perceptual capabilities of the animal. Many animals employ eyes as their primary sense organ and perceptual information is extracted from retinal images. In a VR system, such "retinal" images correspond to the 2D projection of the 3D virtual world rendered from the point of view of the artificial animal's "eyes". However, many animals do not rely on vision as their primary perceptual mode, in which case vision models alone may not be able to appropriately capture the animal's perceptual abilities.

It is equally important to model the limitations of natural perception. Animal sensory organs cannot provide unlimited information about their habitats. Most animals cannot detect objects that are beyond a certain distance away and they usually can detect moving objects much better than static objects [14]. If these properties are not adequately modeled, unrealistic behaviors may result.

Moreover, at any moment in time, an animal receives a relatively large amount of sensory information to which its brain cannot attend all at once. Hence there must be some mechanism for deciding what particular information to attend to at any particular time. This process is often referred to as attention. The focus of attention is determined based upon the animal's behavioral needs and is a crucial part of perception that directly connects perception to behavior.

Unfortunately, it is not at all well understood how to model animal sensory organs, let alone the information processing in the brain that mediate an animal's perception of its world. Fortunately, for our purposes, an artificial animal in its virtual world can readily glean whatever sensory information is necessary to support life-like behavior by directly interrogating the world model and/or exploiting the graphics-rendering pipeline. In this way, our perception model synthesizes the results of perception in as simple, direct and efficient a manner as possible.

The perception system relies on a set of on-board virtual sensors to provide sensory information about the dynamic environment, including eyes that can produce time-varying retinal images of the environment. The brain's perception control center includes a perceptual attention mechanism which allows the artificial animal to train its sensors at the world in a task-specific way, hence filtering out sensory information superfluous to its current behavioral needs. For example, the artificial animal attends to sensory information about nearby food sources when foraging.

4.4 Behavior System

The behavior system of the artificial animal mediates between its perception system and its motor system. An *intention generator*, the animal's cognitive faculty, harnesses the dynamics of the perception-action cycle and controls action selection in the artificial animal. The animator establishes the innate character of the animal through a set of *habit parameters* that determine whether or not it likes darkness or whether it is a male or female, etc. Unlike the static habits of the animal, its mental state is dynamic and is modeled in the behavior system by several *mental state* variables. Each mental state variable represents a distinct desire. For example, the desire to drink or the desire to eat. In order to model an artificial animal's mental state, it is important to make certain that the modeled desires resemble the three fundamental properties of natural desires: (a) they should be time varying; (b) they should depend on either internal urge or external stimuli or both; (c) they should be satisfiable. The intention generator combines the habits and mental state with the incoming stream of sensory information to generate dynamic goals for the animal, such as to chase and feed on prey. It ensures that goals have some persistence by exploiting a single-item memory. The intention generator also controls the perceptual attention mechanism to filter out sensory information unnecessary to accomplishing the goal in hand. For example, if the intention is to eat food, then the artificial animal attends to sensory information related to nearby food sources. Moreover, at any given moment in time, there is only one intention or one active behavior in the artificial animal's behavior system. This hypothesis is commonly made by ethologists when analyzing the behavior of fishes, birds and four-legged animals of or below intermediate complexity (e.g. dogs, cats) [15, 16]. At every simulation time step, the intention generator activates behavior routines that input the filtered sensory information and compute the appropriate motor control parameters to carry the animal one step closer to fulfilling the current intention. The intention generator Primitive behavior routines, such as obstacle avoidance, and more sophisticated motivational behavior routines, such as mating, are the building blocks of the behavioral repertoire of the artificial animal.

5 Interfaces

Because it is our past experience that all technology much be bulletproof and withstand the rigorous demands of an unrelenting public, this equipment is designed along the lines of actual DIVE equipment which is very durable and rugged, big and easy to use.

5.1 Tracking/Sensing

A number of tracking options are available, his environment will consider the use of mix from magnetic [17], to un-encumbered technology such as camera based systems [18]. Sensing the bulk of visitors is done with infrared and video. Specific occupant tracking is done either with localized gloves cabled to the specific site location, or through wireless. Shutter glasses should be independent and able to sense any WALL or CAVE. Artificial Life use sensing to establish the location of visitors within the environment and can respond to them as a normal fish would respond.

5.2 Weight Belt with Dive Panel

This equipment enables visitors to interact with the environment and gain statistical information about the life species in the installation. The weight belt holds the battery pack and wireless communications, tracking and wand/pointer hardware, and a smart/memory card slot for recording individual data and experiences. Attached to it is a "Dive Panel" which is a pointing wand, and small LCD monitor to display information about the species that are under investigation, and other climatic information. Through this, the visitor is able to access the knowledge base stored on the memory card and other data being generated real-time.

5.3 Enhanced Shutterglasses

Shutter glasses are connected to a timer so that when the visitor's use all their "air", they shut down and are inoperable. This makes the environment very difficult to see and forces the visitor to exit the installation. Some of the more sophisticated models for avatars and "Marine Biologists" have audio communications built in.

5.4 Taking Home a Bit of the Virtual Reef

Something else that we think is really important from NICE is giving people some kind of artifact from the experience. Since VR is such a rare experience, and you really can't take anything physical away from the virtual space, it helps people when they try to describe what they did to other people, and enhance the experience and memory of the event.

Each participant in the virtual reef environment gets a smart/memory card to record a "narrative" of everything they did, characters they talked to, actions they performed.

The narrative structure captures these interactions in the form of simple sentences such as: "Mary (disguised as a dolphin) stops by to see Murray the Moray eel to find out what he eats. Mary and Murray have dinner together."

The story sequence goes through a simple parser, which replaces some of the words with their iconic representations and stores the transcript onto their Memory card. This gives the story a "picturebook" style that the visitor can print out and keep to remember the various aquatic life they met that day.

5.5 Smart/Memory Cards

We are currently investigating the use of Smart/Memory Cards to perform functions like: tracking and recording the user's actions, supplying a knowledge database, and providing financial calculations for visitation fees.

6 Interactivity

6.1 Visitor Interactivity

Avatar: There are many species in which a visitor can explore, from fish and other animals. Avatars can be as simple as the ones found at the localized exhibits for tourists to try out, to the sophisticated ones like dolphins and sharks. Avatars ultimately come under the domain of the simulated eco-cycle, so anything could happen: the visitor's avatar could be eaten at any time, and eventually will go through the entire life cycle of the reef.

Snorkeler: This level is simple roaming and exploring the environment with minimal hardware, such as shutter-glasses to immerse them in 3D. The smart card enables them to utilize the local interactive stands available throughout the environment.

Marine Biologist: This level of interaction is highly independent and is able to program their own interactivity levels for simulation, planning, studying, etc. The equipment this visitor has is the most advanced versions of the standard models.

6.2 Artificial Life Interactivity

The artificial life in the environment is just as interactive towards visitors as visitors are to them. They can and will interact with visitors in many different behaviors, from being friendly, territorial, viscous, funny, etc. Fast movement will scatter fish. In this way, true interactivity is two-way, creating a complex environment.

6.3 Staff Interactivity

Guides: These are sophisticated avatars that can interact with anyone in the environment. These people can be in the environment or hidden from view. They have audio and visual communication devices to drive avatars such as Mermaids, large fish, human animations or indigenous characters. This level of interactivity can be used for guided tours, assistants, observers and other special requirements. At this level, the guide is able to leave discovery objects which visitors can touch and find out more information.

7 Conclusion and Future Works

This system has been designed using existing and known solutions of virtual reality, networking, evolutional theory and artificial life, and yet, the innovation lies within the organization of each application into complexity. It has been designed with the forethought of being able to use the physical architecture as a generic shell to enable other stories besides the reef to be told, and the application able to be used in other systems, including retrofitted Planetariums.

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The Development of an Intelligent Haulage Truck Simulator for Improving the Safety of Operation in Surface Mines

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Abstract. Surface mines are in operation world-wide, the vast majority employ large haul trucks for the transfer of material both to the outside world and around the site. The sheer size of these trucks and the operating conditions means there is a high level of risk. Allied to this, the commercial nature of the operation means that down time is extremely costly and driver training expensive. The AIMS Research Unit has developed a PC based system to improve driver training which is currently being developed into a commercial application.

Scenarios are created by importing site specific data through industrial CAD systems, road systems are then added through an editor to create good replicas of the environment facing drivers on a day to day basis. The world is further enhanced by allowing the user to specify a number of intelligent objects including haulage trucks, excavators with load points and various static objects.

Once scenarios have been created training is carried out on a full screen real time simulation which allows trainees to drive or be driven by computer through the world. At any given point the trainee is able to stop the simulation and identify potential hazards, their associated risk, and take possible corrective action.

Keywords: Driving Simulators, Safety Training, Virtual Reality, Hazard Awareness, Surface Mining.

AIMS Unit

The AIMS Research Unit at the University of Nottingham has been involved in the fields of computer graphics and virtual reality for a number of years and has identified a number of potential applications for the engineering industry. In particular it now appears that the technologies have developed sufficiently and costs reduced to levels that mean even the smallest companies can seriously consider them.

J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 337-344, 1998

The AIMS Unit uses a range of commercial packages and programming languages to create new computer based applications. Development takes place on both PC and Silicon Graphics platforms. However the unit has found that systems developed using PC technology are more easily ported to the industry due to reduced costs, the existing user base and the familiarity of PC technology [1].

Background

There are many surface mines in operation throughout the world, all of these require the safe transfer of material around the site. In many cases this is achieved by haulage trucks, these large vehicles, often the size of a small house, have many associated safety issues.

Their huge size together with the difficult environmental conditions introduces handling and visibility problems. There is a high level of risk associated with each truck, as the consequences of an accident can be extremely severe. Strict operational rules are enforced to minimise the potential for disaster, whilst these have been successful in reducing accidents, by 1995 industrial trucks were still the second leading cause of fatalities in the private sector behind only highway vehicle fatalities [2]. Indeed the OHSA found on average 107 fatalities and 38,330 injuries occurred annually in the workplace, furthermore it found present training standards to be ineffective in reducing the number of accidents involving powered industrial trucks.

At the moment only trained operators can drive these trucks, periodic evaluation of each truck drivers performance is also required. Competency will depend on the ability of the vehicle operator to acquire, retain, and use the knowledge, skills and abilities that are necessary.

Financially, haulage trucks are the largest cost item in the operating costs of a surface mine in some cases accounting for an estimated 50% of operating costs [3]. The large initial cost of these trucks also makes driver training expensive.

Attitudes towards industrial safety have advanced significantly in recent years and the mining industry has not been an exception to this. The introduction of new legislation in the UK [4] has changed the emphasis of industrial law from prescriptive legislation into new management systems.

Large mineral organisations are now continually looking for ways to improve their safety performance and techniques, which may help to reduce accident statistics, need to be investigated. The capacity to remember safety information from a three dimensional world is far greater than the ability to translate information from a printed page into a 'real' three-dimensional environment [5].

AIMS Unit Truck Simulator

System Details

The system has been designed to run on a PC platform, prospective users identified this as particularly important due to the wide availability and low cost of the platform. The system used for training operates as a full screen application and provides both visual and 3D audio output. Trainees are able to interact with the system in a number of ways including through a custom built steering wheel and pedals.

The system is split into two modules, the first is an editor allowing the trainer to configure and save a number of different scenarios, the second runs as a full screen simulation during training sessions. Both parts have been programmed in Visual C++ and DirectX is used as the graphics and sound API, this allows access to acceleration across a wide range of hardware.

System performance varies according to the size of environment, however advances in graphical accelerators mean that high frame rates have been maintained despite using large pit meshes. The system has a high level of graphical detail, this is quite important during the process of training as it is often the ability to spot visual details that ultimately leads to safe operation.

World Modelling

As mining progresses from phase to phase, haul road networks and truck routes must adapt as the landform changes. To create more relevant training scenarios, it was important that the trainer should be able to accurately recreate the work place and conditions. This ranges from road layouts, truck movements and loading points through to lighting and fogging conditions to simulate different weather conditions.

The application we have developed reduces the cost of creating new worlds by using currently available pit data. Surface mine operators maintain 3D models describing the development of the terrain and possibly haul road layout for each distinct operating phase. These are maintained in industry standard modelling packages such as Vulcan or Surpac. Mesh data held in these packages can be exported directly into the system and used as a base mesh for the virtual world.

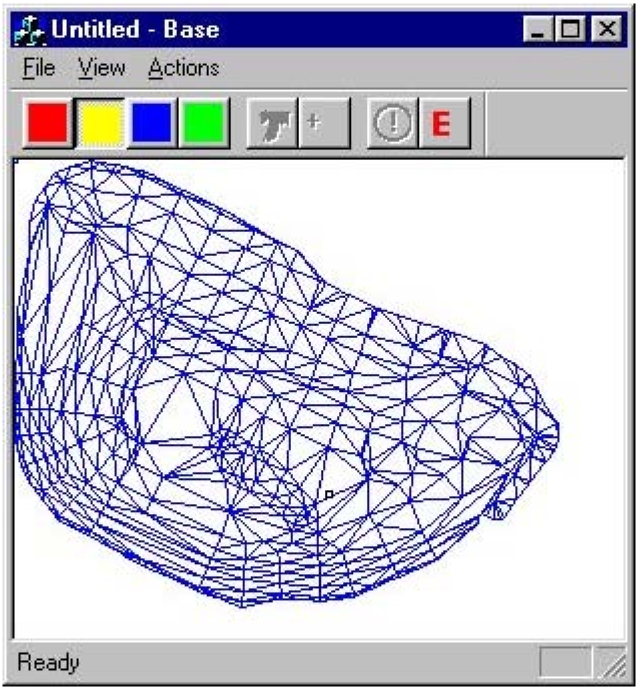

Fig. 1. 2D pit during configuration

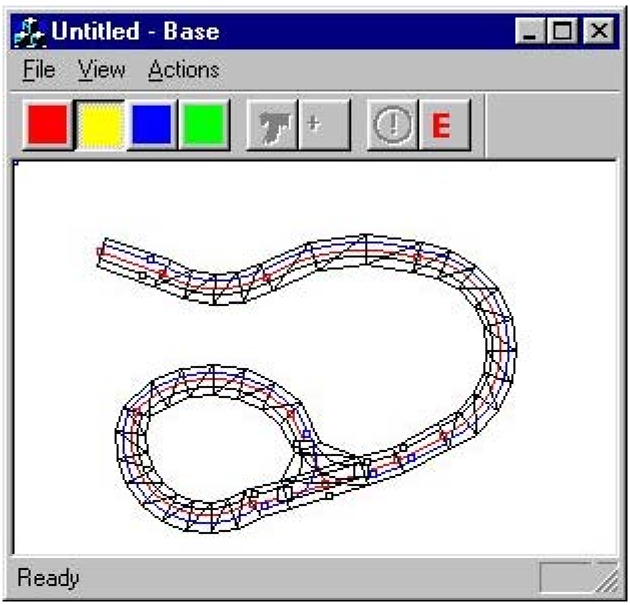

Fig. 2. Construction of the haul road

Haul road information is overlaid using 2D drawing tools, it is then converted to a 2D road system, before being subtracted from the base model. Height values for the haul road are obtained through an averaging process on local vertices, smoothing also takes place on each segment of the road so that the surface remains flat. The road system is then re-triangulated back into the original mesh and textures are applied to both. This process creates a haul road system consisting of a number of straight, curved, and multiple exit junctions, this not only helps to reduce the polygon count but also to reduce the computational overhead during simulation.

Fig. 3. Textured pit and haul road

All further objects, their attributes and behaviours are added into the scenario at this stage by clicking on a 2D plan of the environment, the third height dimension is automatically calculated. The addition of objects and the configuration of their behaviours has been kept as simple as possible to reduce the complexity of defining new scenarios.

Haulage trucks are added by indicating the start, finish and waypoints through which they must pass. Excavators are added by defining the segment in which they load and the direction from which trucks approach. Other objects, such as Surveyors, parked vehicles and road signs are added in plan view and their associated height values are again calculated. Further haul road system details can also be configured, this includes assigning priority at multiple exit junctions.

Intelligent Behavioural Modelling

Truck position and velocity is calculated in real-time and is based on industry standard rimpull and retarder curves, these together with factors such as mass, and

gradient provide an accurate simulation. Interaction with surrounding objects is also taken into account before updating a truck's position.

Trucks attempt to follow user-defined routes based upon the road network that has been created, these are pre-calculated as far as possible by storing an ideal line which the trucks attempt to follow. Trucks will take a predefined route through the pit to the load point, where they queue to be loaded before proceeding to the dump point, and the cycle begins again. Trucks also have the intelligence to modify their position, velocity, and acceleration during the simulation according to the state of localised equipment. Figure 4 shows an example of multiple computer-controlled trucks queuing to be loaded. The simplification of the haul network allows extensive details as to the position of the truck within each segment to be monitored as well as allowing the truck to look ahead analyse potential situations and adjust its behaviour accordingly.

Fig. 4. Trucks queuing to be loaded

Training Methods

Trainees may either drive or be driven (by the computer) around a pit. Training is primarily achieved through a technique termed 'hazard spotting', this allows the user to identify a number of pre-determined hazards which are included in the virtual world. As the trainee passes through the pit they are able to stop the simulation at any time to 'spot' these hazards. Once identified, they are asked to classify the hazard in terms of risk, and indicate any corrective action which should be taken. Performance is recorded and responses assessed against ideal behaviour. Figure 5 shows such a choice being made.

Fig. 5. Risk choice being made

Future Work

Work is currently being carried out to improve the current system and also to extend its scope. Proposed is a pre-start up equipment check allowing the trainee to inspect his vehicle prior to entering the simulation. Planned improvements for the current system include the use of multiple monitors to provide additional viewpoints and using aerial photographs as textures to overlay the pit. Development is also being carried out on using similar techniques in other industrial environments.

Conclusions

Virtual reality seems to be an ideal way of exposing trainees to hazardous situations without ever putting them at any real risk. Additionally a large number of potentially rare circumstances can be experienced in a relatively short period of time. However,

there is still doubt as to how well these skills transfer to the real world. Work with other vehicle simulators indicates that there can be a significant reduction in accidents [6] so it would be reasonable to expect similar results.

The system has yet to receive field testing, however it has been demonstrated to a large number of mining institutions whose response has been very positive. Representatives particularly liked the fact that they could create and configure multiple scenarios from existing CAD data quickly and easily. It is anticipated that the system will be commercially available in the next few months.

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Navigation in Large VR Urban Models

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Abstract. The aim of this research project is to utilise VR models in urban planning in order to provide easy-to-use visualisation tools that will allow non-experts to understand the implications of proposed changes to their city. In this paper, the navigation problems identified whilst working on large VR city models are discussed and a "fly" based navigation mode is proposed and evaluated.

1 Background

The Centre for Advanced Studies in Architecture (CASA) has been involved in three-dimensional (3D) computer modelling for the last six years. In 1991 CASA received a grant to construct a 3D computer model of Bath [2]. The project was supported by Bath City Council and since its completion the model has been used by the city planners to test the visual impact of a number of proposed developments in the city. The model was created from aerial photographs of the city in 1:1250 scale using a stereo digitiser. It is accurate to 0.5 metre and covers the whole historic city centre, an approximate area of 2.5x3.0 km. During 1995 and using similar techniques, the core of London's West End covering 1.0X0.5km was also modelled followed by Gloucester city centre in 1997.

Following the hardware and software developments of the last few years, the expansion of the Internet and the World Wide Web (WWW) and current trends in the industry, the Bath and London model were translated and are used non-immersively in VRML as well as custom made VR applications [2][3]. The initial problem faced was how VR applications would scale and adopt to visualising a whole city of over three million triangles as in the case of Bath. The Bath database is, to the author's knowledge, the largest and most detailed one produced as yet; the UCLA Dept. of Architecture and Urban Design (AUD) is currently building a model of the entire Los Angeles basin covering an area in excess of 10000 square miles as part of "*The Virtual World Data Server Project*" but it is still under construction.

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2 Utilising VR Urban Models

The computer models created in CASA demonstrate how computers will be used in the near future by engineers as part of their everyday practice, creating, modifying and improving our cities online using centrally stored sharable databases. The aim is not to create yet another Geographical Information System (GIS) although GIS features can be incorporated. Using Internet compatible programming languages such as Java, Cobra or ActiveX, VR urban models can replace a dedicated GIS system for certain applications (London's West End). It should be noted that due to the nature of the proposed use of the models, the low polygon count fully texture mapped model approach adopted by more commercial/advertising oriented projects (Virtual Soma, Virtual LA etc.) was not feasible.

The Bath model has been used in a variety of ways since it was originally constructed. To date, development control has been the main use with a number of schemes being considered. These are normally at the instigation of the local authority who recommend that schemes are modelled in order to facilitate discussions during the design phase and for presentation to the planning committee. In addition to its use in development control, the model has also been used to widen the public debate on how the city should develop in the future.

The model of London's West End is of lower level of detail and was initially used for transmitters' signal propagation experiments by British Telecom (BT). CASA has been using it as a database front end to navigating and mapping information on the city thus creating the Map of the Future. Gloucester's city centre model which was commissioned by the Gloucester City Council is used for planning control similarly to the Bath one.

3 Navigation Problems

Early in the process of creating VR models, the problem of navigation was identified together with inconsistencies on texture mapping, instancing, materials, indexing, etc. Although most of the problems were solved [9], navigation remains a troublesome experience not only to occasional users of the VR models but to the creators as well.

The main problem in exploring, navigating and generally working with urban models in a VR environment (both immersive and non-immersive) is orienting oneself; being able to identify areas, streets, buildings etc. Therefore, a great deal of effort has been put towards making urban models more recognisable. It should be noted that there is a great difference between pursuing realism and aiming for a recognisable virtual environment (VE); a VE does not necessarily imitate reality [5]. Creating realistic VE of such scale is still not feasible and in many cases both pointless and inappropriate.

In real life, when a person becomes disoriented in a urban environment, the natural action taken is to scan the surroundings searching for *information.* As Lynch [14]

explains, there is a consistent use and organisation of definite *sensory cues* from the external environment.

Assuming no external help is requested, this activity comprises of three steps:

- Look around
- Move around within a small radius
- Wander further away with the added complexity the person may subsequently fail to return to the original position.

Failure of the above three steps means that more drastic ones must be taken. This typically involves interaction with other people asking shop owners, pedestrians, car drivers, etc. for the relevant information. Alternatively, one could check road names against a map, in extreme cases even consult a compass.

3.1 Current Trends

There have been many attempts, both commercial and theoretical, to create and interact with informational spaces [6]. Techniques have been developed based on both “realistic” and “unrealistic” concepts but it seems there is no consensus as yet. Putting aside the information space metaphors used, the navigation metaphors employed can be classified in two main categories; the *screen* and the *world* based ones. Among the former is sliding, rolling and examining whereas the latter include walking with or without physical constrains (gravity and collision detection), flying above the landscape and above the roof line utilising a bird’s eye view of the city and borrowing from cinematic terminology, panning and tilting.

Game development is an area that one can review design decisions; a very efficient, demand driven, competitive environment enforcing quick, effective development cycles.

Early 3D games like Doom and Descent, where the focus was on speed and interactivity, featured fairly simple environments. Each stage had an average of 10-20 rooms/spaces with quite different shapes, textures and themes in general. Furthermore, the overall settings for these games were not real 3D; players could not share plan co-ordinates (XY) with different elevations. The cues facilitating navigation were plenty, with the different types of enemies and, in some games, even their corpses adding to the amount of visual information available. Auditory cues were vital in sensing events that took place in secluded areas or simply behind the players' back. In such games a 2D wireframe plan of the site was the only navigation hint given to the players and was usually enough to get them back in course.

In the more recent “action” games like Tomb Raider and Tie Fighter, the following important differences can be identified:

- The player’s avatar is fully included in the VE. The player is not a spaceship dashboard or a weapon carrying hand anymore but a fully articulated avatar giving better sense of scale and participation [11]
- More advanced navigation aids are used (notably compasses, text narration, lighting, sound etc.)
- Real-time rendering of texture mapped animated characters

- Collision detection and gravity
- "Director's" Camera Movement. Camera zooms and moves around the action (that is the player's avatar) creating a feeling of a well-directed action movie rather than a simple game playing (Tombraider). Subsequently, wandering in the rooms becomes a worthwhile experience itself!

The scale issue addressed with the full avatar presence is the most notable improvement together with the use of perspective and camera movement to follow the action. The above mentioned points can be and in a few cases are already employed in VR urban models' interface. Information providing with position and orientation of the user visible as well as custom dashboards featuring compasses are possible. Additionally, audio data, animated objects can be incorporated.

3.2 "Flying" Modes of Interaction

In this paper, the focus is on the implications of employing a "flying" based navigation mode. It is argued that due to the lack of sufficient detail at street level, the "identity" and "structure" of the urban image is much "stronger" from an elevated position, when more distant cues are visible. This is especially true in the CASA built models considering the fact that the 3D models were created from mainly aerial information; facade surveys were carried out but the main core of information came from stereo pairs of aerial photographs. The roofline is very accurately represented in geometry and colour without the need for textures or complicated geometrical hierarchies. In many cases, roof level detail had to be eliminated in order to keep an overall balance within the VE.

Among the problems linked to the "fly" mode is that it effectively removes any degree of immersion by switching the person to map reading mode (some will argue that it furthermore defies the reason of having a VE in the first place). Prior knowledge of the city is advantageous whereas there is a distinct lack of sense of time and effort needed to travel over a VE.

Furthermore, according to Ihde [12] there is evidence that there are important connections between the bodily-sensory perception, cultural perceptions and the use of maps as navigational aid. He relates the bird's eye view of flying over a VE to the God's eye map projection identified in the literary cultures. This mode of interaction has definite advantages although it also introduces an often-unknown perspective of the city. This perspective is more accessible to engineers and architects who are used to working with scale models of sites which inherently introduce the bird's eye view. According to Tweed [18], the relationship between flying and walking modes should reflect to orientation of the body position, making flying modes more akin to immersive VR systems.

It should be noted that it is possible to add street level detail in order to improve the amount of information -sensory cues available by adding:

- Street furniture (lamp-posts, phone-boxes, bus stops, litter boxes, road signs, tarmac markings …)
- Building detail (Textures + geometry)

- Animated elements (vehicles, people, etc.)
- 3D Sound and pre-rendered shadows
- Trees, landscaping, flowerbeds etc.

However, more often than not, time and cost constrains prevail (surveying and modelling are both costly and time consuming) not to mention the hardware platform limitations [13]. Adding street furniture, landscaping and animated elements puts the burden on both hardware and software. Frame rate is an issue; from experiments carried out already in CASA, the indications are that 5-6Hz is the lowest acceptable level for such applications assuming the key issues addressed above are catered for. However, frame rate is not the most important variable in urban scale models—a 30Hz VE of an inferior model lacking the key issues is not a satisfactory solution.

It should be noted that urban VE rely very heavily on visual cues in many cases ignoring the fact that aural cues could be more powerful and helpful [7]. This can be credited to the fact that most such models are created and used by architects and engineers in general who are traditionally not taught to understand and appreciate the importance of sound in an environment, even more so in a VE.

3.3 Limitations of Non-immersive VR

VR models that are used in a team evaluation environment are usually non-immersive. The main reasons are practical; if all the committee members are to be gathered together in one room, the amount of hardware and cables running on the floor, the size of the room and the overall support required is unfeasible. The cost of the necessary hardware to provide a fully immersive experience for half a dozen planners and other committee members is prohibiting. Finally, the need for interaction and communication while evaluating a scheme and the need for a common reference point when assessing a particular feature would be extremely difficult to achieve in an immersive environment [1]. For such tasks, the Reality Centres that Silicon Graphics Inc. has created are ideal; pseudo-immersive double curvature, wide screen displays with a single operator. On the downside, the assessors' team has to travel to the particular site (only a handful in the whole UK) and the costs involved are outside the budget of a City Council or local authority.

Nevertheless, there are important navigation advantages to be obtained on a single user immersive VE as opposed to a multi-user one.

One of the problems identified in early experiments is the lack of concept of time and distance. Walking on the streets of a virtual city is an effortless exercise in contrast to the real experience. It is possible to fly over a whole city model in a matter of seconds and that can be instrumental on loosing both orientation and sense of presence. Recent attempts in immersive VE tried to introduce body interfaces to navigation. Shaw [16] used a bicycle as the metaphor for navigating in his installation *The Legible City*. This way, the pedalling speed sets the speed of movement whereas the handlebars determine the direction. Another metaphor used with movement tracking devices is that of walking on the spot [17]. The pattern of body movement relates to pre-computed patterns and determines whether the user walks, runs or steps

back. Char Davies has created a synthetic environment called “Osmosis” [8] exploring the relationship between exterior nature and interior self where the immersant’s body movements are triggering series of events that position the body within the VE and even alter the environment itself.

Among the first techniques employed in the Bath model in order to improve sensory cues from the environment was the use of wide angle lens; the argument being that this way a greater part of the city is visible and thus more information is transmitted to the user. However, the results of a small scale case study with university students of architecture and other members of staff familiar with the city where discouraging. Architects identified the problem as being that of “wrong perspective” compressing the depth of the image and generally creating a “false” image of the city. Others could not easily identify the problem but found the environment confusing nevertheless. Consequently it was decided to use only the “normal” lens on all VR projects although it does limit the perceived field of view which in real life is much higher than 45 degrees. Experiments on level of detail degradation in the periphery of head mounted displays (HMD) [19] as well as eye movement and feedback [4] demonstrate that more efficient VR interfaces can be achieved (compared to non-immersive ones) without necessarily hitting on the main VR problem; CPU capabilities.

Another problem faced in non-immersive VR is that of the direction of movement versus direction of sight. Due to the two dimensionality of the majority of input devices used in non-immersive VR, it is assumed that the user looks at the exact direction of the movement. This is quite true in most cases, but when one learns and investigates a new environment, movement and direction of viewing should be dealt as two individual variables. Immersive VR headsets with position and orientation tracking mechanisms are again the easiest and more intuitive solution to this problem.

Therefore the *Variable Height Navigation Mode (VHNM)* is introduced as another solution to the problem.

4 Variable Height Navigation Mode

The VHNM is based on the fact that at any given position in a urban model, there must be a minimum amount of information - sensory cues - from the external environment available to assist navigation. This can be achieved by adding enough information on the model although this is rarely an option as was discussed earlier. Alternatively it can be achieved by varying the height of navigation according to the amount of sensory cues available on any given position.

As an example, a wide long street with a few landmarks will bring the avatar down close to street level, whereas a narrow twisted street in a housing area will force the avatar high above the roof level.

4.1 Theoretical Model

In the real world, the sun, the wind, a river, the sound emitted from a market or a busy street, a church, a building, a street, a road sign, a set of traffic lights are among the *sensory cues* accessible and used by people. Furthermore, each person gives different importance to each of them making the whole process of classifying and evaluating visual cues much more difficult. In a VE, which is generally much less densely occupied and furnished by the above-described elements, classification is relatively easier. Although the user must be able to rank the relative importance of the various cues available, the designer of the VE can assign with relative safety *what is* a sensory cue within the VE.

The theoretical model proposed uses a series of gravity like nodes or *attractors* [7] that pull the avatar towards the ground when approaching an area of high density in sensory cues. Similarly, in low-density areas a global negative gravity pulls the avatar towards the sky until there are enough sensory cues nodes visible to create equilibrium. It should be noted that the *attractors* are not true gravity nodes since they can only affect the elevation of the avatar and not its position in plan.

The first emerging issue is that of cues' visibility. In order to identify the visual cues available from each position the field of view and the direction of viewing is considered. Following, a ray-tracing algorithm is employed in order to assess visual contact from the current position. Considering the size of the object, a series of rays must be calculated to establish the percentage visible from the current position.

Relative importance of the visual cues is essential if the model is to be successful. A general ranking of them can be carried out by the world designer based on the size, form, prominence of spatial location, historic value, users awareness, etc. However, the navigation mode proposed should be flexible enough to accommodate particular needs of the users. Locals will use completely different cues (depending on the culture, could be pubs, churches, prominent buildings, etc.) to the first time visitors who will probably opt for the ones described in their guide books and the ones that possess the main landmark characteristics as defined by Lynch [14].

Another variable relates to the amount of visual cues users received over time while navigating in the VE. The higher the amount the better the mental image of the city they have created. According to Lynch [14], sequential series of landmarks where key details trigger specific moves of the visitor is the standard way that people travel through a city (p.83). VHNM keeps track of the number of visible cues, their distance from the users' path the speed and direction of movement and finally the time each one was visible. All that can recreate the path followed and should enable the prediction of areas of potential problems and modify the current elevation accordingly. In the event of orientation loss, it would be possible to animate back to a position rich in visual cues, a kind of an 'undo' option. The main question in animating back to a recognisable position is whether the user should be dragged backwards (as in a process exactly reverse to the one they followed) or if the viewing direction should be inverted so that a new perspective of the city is recorded. The argument for the former is that the user will be able to directly relate to the actions

taken only minutes ago, whereas the latter has the advantage of showing a new view of the city and the disadvantage that the process of memorisation may break down.

Consequently, the VR application can be trained over a period of time and eventually be able to react and adjust to the habits and patterns followed by each user. Keeping track of the time spend on particular areas of the VE will enable the computer adjust the avatar's position on the assumption that the recognition process and memorisation will strengthen the more time one spends at a particular place within the model.

The tilt of the viewing should be also briefly considered. Walking at ground level and looking straight ahead is what people are used to, but when one is elevated twenty, thirty or more metres above the ground level the perspective distortion introduced by tilting and looking downwards should be considered. As described earlier, an often unknown perspective of the city is introduced and the effects it may have on different users should be carefully evaluated.

Concluding, the theoretical VHNM model proposed will be quite difficult to implement in real time with existing computing power in large VR urban models. It is currently an extremely difficult task to structure the geometric database alone; setting up all the raytracing calculations and the fairly complex set of rules described above will seriously affect the performance of any VR application. However, some problems may be alleviated by reorganising the scenegraph, which conflicts with the general concept of spatial subdivision of large VR models and their organisation in Levels of Detail as discussed extensively elsewhere [2],[3].

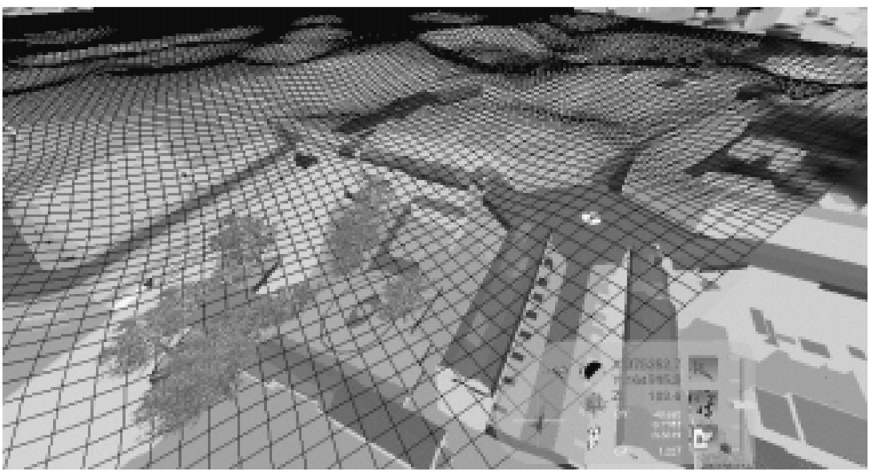

Fig. 1. VHNM mesh on the Bath model. Typical view

Finally, it should be pointed out that the focus of this paper is limited on the visual cues. Experiments are still to be carried out regarding the employment of auditory cues in an urban VE.

4.2 Model Implemented

Having described the ideal system an attempt is made to put it into practice. Bearing in mind the difficulties in implementing the original concept, a collision detection based navigation mode is initially proposed (Fig. 1). A transparent and thus invisible mesh is introduced, “floating” above the urban model. The peaks of this mesh are where the minimum amount of sensory cues are, so in a way it is an inverted 3D plot of the sensory cues against the 2D urban plan. Using a 2D device, such as a mouse, it is possible to navigate in the VE whilst collision detection against the invisible mesh determines the elevation of the viewer (Fig. 2).

a. **b.**

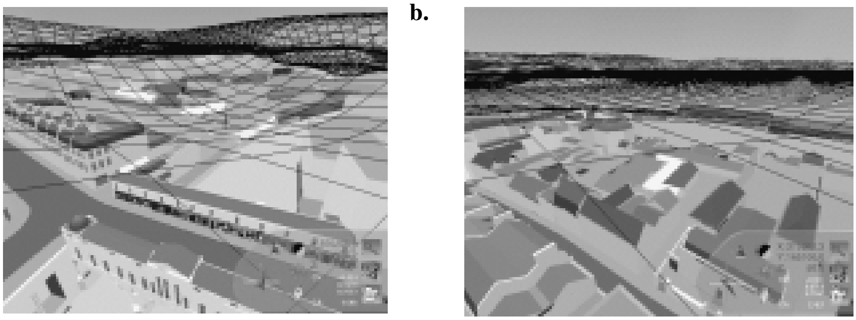

Fig. 2. VHNM views on **a.** high and **b**. low visual cue areas

Early in the development stage, it was decided to represent the VHNM mesh as a visible five-metre wireframe grid, giving users a reference point to the height they are and an extra orientation directional grid. Consequently, the VHNM mesh clearly denotes which areas of the model are lacking sensory cues and by creating visible peaks on them, it actually presents cues of its own to aid orientation and exploration. Following extensive testing, it was concluded that for the Bath model, areas rich in sensory cues can be successfully explored at a height of 25 to 35 metres above street level (10 to 15 metres above the buildings' roofline). Regarding areas that proved problematic in the initial navigation experiments, 40 to 50 metres above street level produced good results. It was attempted to keep the height variation to distance ratio as low as possible to avoid user confusion and make navigation and movement smoother. It should be noted that the values mentioned above were satisfactory in the particular urban model but it is unlikely they will be suitable for a high-rise or a very densely built area. Experimentation will provide the right values and most likely a mathematical model will be developed once the VHNM is tested on London's West End and Gloucester City centre models also developed in CASA.

In order to accommodate for the different needs of varying groups of users, the VHNM mesh can be shifted along the height axis (Z) according to the familiarity of the user to the urban model presented (Figure 3c,d) using on screen controls. It is also possible to alter the scale of the mesh along the Z-axis. Doing so, the viewer drops lower closer to the ground on areas rich in sensory cues and flies higher on

poor areas (Figure 3a,b). The first experiments carried out using the manually created VHNM meshes were quite successful in reducing the amount of confusion and orientation loss. However, no statistical analysis of the data obtained has been carried out yet, since controlling such an experiment proved extremely difficult. Consequently, most of experimentation was used for fine-tuning the technique and the variables involved. A series of tasks are currently being developed in order to create a more controlled environment enabling drawing of conclusions on the effectiveness of the proposed method and creating a test bed for evaluation of future work.

a. **b.** **c.** **d.**

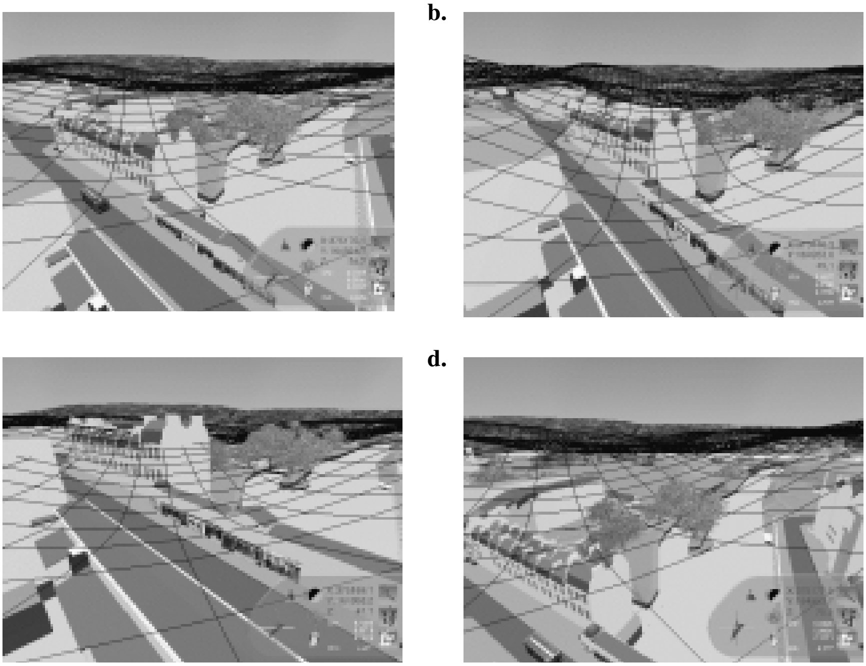

Fig. 3. VHNM Editing options, **a.** normal, **b.** scaled up, **c.** shifted down, **d.** shifted up

Among the limitations of this implementation is that the computationally expensive ray-tracing calculations needed to accurately create the mesh, were approximated in advance manually. Consequently, the already complicated and difficult job of the VR application is not stressed any further by having to compute gravity nodes and search for cues in the VE. However, generating this mesh is a very laborious process and difficult to automate. Furthermore, the VHNM mesh completely disregards the avatar's viewing direction. In most positions within an urban model, the cues available are strongly related to the viewing direction. Looking north may give no clues whatsoever whereas turning 180 degrees and facing south may reveal the position of the sun (at least in the north hemisphere) and a landmark

that will let you pinpoint your position on a map. Users have no option to classify the relative importance of the type of cues available according to their own needs. It is a pre-calculated VE that one is only allowed to navigate in, which is conflicting with the general conceptions of the service computers should be providing [15].

The next step will be to incorporate the visual cues versus time variable in the model and investigate to what extend the behaviour of a visitor can be predicted and augmented. Following, auditory cues will be included while work will be carried out into finding ways to simulate more accurately the theoretical model proposed.

5 Conclusions

The proposed VHNM can solve certain problems in urban VR environments and if implemented fully could be a very successful navigational tool. However, bearing in mind the complexity of the proposed model, an immersive VR environment would supplement a partial implementation of VHNM more economically, in terms of cost, ease of programming and time needed to construct and fine tune the VR system. The implementation problems of the proposed VHNM can be tackled with different degrees of complexity and accuracy according to the capabilities of the VR platform used.

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Virtual L.A.:	http://www.gsaup.ucla.edu/bill/LA.html
Virtual Soma:	http://www.hyperion.com/planet9/vrsoma.htm

Art and Virtual Worlds

Olga Kisseleva

Today`s world is characterized by an explosion of new communication technologies and unique uses which modify our behaviour and our thought processes. Confronted with this evolution, we are waiting for a new form of life to emerge corresponding to these technologies. A new art form corresponds to this existence, not merely by tools that it uses but through the questions that it raises.

We can thus note that with the intervening changes in society, scientific progress, and the change in the general relation between art and life, the artist's role today is radically new. Contemporary art has changed its function in relation to modern art in the sense that it resembles more and more a science.

Since its conception, art has appeared as a representation of a life ideal, relative to one time. Contemporary art doesn't reflect life. It prefigures it. At present , thanks to the new digital technologies and communication,art itself can become a simulation of reality: an immaterial digital space which we can literally pentrate and,as Fred Forest says, is no longer , a " self-defining form . It is itself a picture, formalized numerically. Dimensional space is no longer an intangible substratum. It is a digital object in interaction with other created objects , having its own reality".

Art exists thus as the counterweight and the complement of science, so that the two together complete the human discovery process. The artist creates, therefore, from concept to analysis while the scientist works from analysis to concept. The artist elaborates a concept as a starting point from which he participates in the construction of a world. If he succeeds in proving the reality of his concept, it will develop to become part of the collective conscience. On the contrary, the scientist analyzes, researches, studies,and experiments before formulating his concept. In this way, science reveals our knowledge of the world , exploring it step by step, while art interests itself with experience of the world,offering us concepts that permit us to glimpse immediately another, more intuitive, vision of the universe.

Finally, the questions that artists ask themselves in their research are extremely close of those of scientists. Communication artists and researchers, working on the problems of communication are confronted, according to Pierre Moeglin, by the same question: In our modern age, to what do we owe this central position ceded to video, to the computer and to telecommunications? Certainly not, they answer, to the sophistication of these technologies, installing a difference of technological application but not of its inherent nature in relation to the previous techniques. Furthermore, we can say that while pushing their limits to phenomena that are not all new - several were already germinating during the first industrial revolution - uses are made systematically revealing better than before the wider

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dimension of diffusion that includes our relation to others and ourselves as well as the access that we have to work, to leisure and culture .

The vocation of art, as well as that of science,has changed. Art`s role is no longer to entertain but to communicate something about the nature of the human mind: the scientist teaches from his scientific paradigm, the artist from his vision of the world.

The different and unique nature of cyberspace permits us to simultaneously approach and escape from reality. Today we are not content with computer-driven animation but moreso with attempting to recreate life, to breathe independant life into these " beings " of pixels and algorithms. It is about giving birth to these " virtual " creatures, capable of learning and evolving.

Virtual reality in relation to the real world implies an isolation. It seems the most obvious expression of a man / machine system in which man plays an integral part. In this universe, movements, or even physiological data and human brainwaves, can be controled by sensory stimulations used like commands. It is a device placed in contact with our body, in our senses, on and maybe one day even under our skin, directly in our brain, if one succeeds in developing brainchips. Some researchers even speak about associating the computer system directly to the human brain. Our senses will then be pacemakers that activate our brain by their signals transformed into electric activity.

More and more realistic "clones", shall circulate throughout the network, with all manners of functionality and with an impressive delegation of power devolving directly from their "game-masters ". The mixture of reality and virtuality applies directly to the creation of cloning. Thus, the putting into movement of virtual actors in real time can be of use in as different domains as teleworking, videoconferences, virtual communities,multiparticipant games or 3D animation. These actors are derived from real faces, then sculpted in 3D before finally being cloned. The animation of clones is produced then in real time: the face of the user drives directly his duplicate with the help of a camera and a treatment of images while the top of the body is directed with the help of two sensors, one on each hand. The user can communicate thus with other clones, to submerge and to interact within a 3D universe.

At the same time, avatars install in the network a new aesthetic that would be the one of Tex Avery with a touch of Tolkien and a personality like the Simpsons. Masters identify more and more with their virtual image, so that avatars impose themselves in their daily life and transform their minds little by little as well astheir own body.

The MUD and the MOO (carrying trades and games in 3D), that are developed in the same way as Internet, evolved in the same sense. Their virtual reality, founded first exclusively on the text, moved toward the conviviality and exchanges ludiqueses with representations in 2D and 3D of users nominees as of avatars.

Artificial comedians also became the object of various researches, in the scientific laboratories and in artistics studio. Interactivity in real time with these comedians became possible with the tele-animation of characters from movements and the mimic of real actors equipped with datasuits and sensors.

Currently, the technical progress, the rythm of life and especially the new technologies of communication, are changing the body. The body is replacing by prostheses. the usefulness of its senses, sometimes leaving only one activated, deconstructed it. The body is seized and transposed in the virtual world, it is cloned and finally it is substituted by a new virtual body, the avatar. The body loses its consistence therefore, its substance, its value, and even its biologic role; it turns into interfacing.

The carnal art, created by Orlan, interrogates the statute of the body at the genetic manipulation age, as well as its future that turns to a gosthly appearance . The virtual, to Orlan, does not only consist to multiply the body and to be telepresent, but also to accept the reconfiguration and the sculpting of the body. For her seventh operation-surgical-performance, implants, normally used to heighten cheekbones, were placed on every side of her forehead . It created two bumps. These bumps, being totally virtual, "avatar ized" the body of Orlan.

As one saw it, the imitation of gestures and even of some human senses is today easy. But the virtual makes also possible the control of senses. Indeed, it reintroduces a kind of individual sovereignty, even though it is rather illusive. Of course, our sensory perception is necessarily coded, because of our cultural, social or personal history. Nor uncertain nor genetic, it is the result of the modelling to which all society proceeds. However, in the virtual reality, this modelling proves to be more restricting, more precise. This testifies well that sensory control is more there a fantasy. Therefore in a reasoning: "The sovereignty of the individual is maybe then restored. But at the same time, his liberty is forced infinitely, since, being not anymore a prey to confusions of the world or of the meetings, he cannot feed himself anymore with their wealth".

Las Meninas in VR: Storytelling and the Illusion in Art

is m iz i n w o nson n istin sil kis

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Abstract. Las Meninas is a virtual reality (VR) artwork based on the painting of the same name by Spanish painter Diego Velazquez. Created for the CAVE(tm), Las Meninas attempts to establish a language of art in virtual reality by placing VR in the realm of storytelling; storytelling that is not simply formalistic and decorative, but also psychological. The viewer confronts a narrative cryptogram which can be deciphered at multiple levels of meaning as he seeks to explore the enigmas inherent in the painting by literally entering into it, both physically and psychologically. This allows for the suspension of disbelief or the illusion in art, the quintessential rule of art.

Keywords

ontologi l ut nti ity kin st ti / syn st ti stimul tion imm sion.

1 Introduction

ny p opl w o v xp i n vi tu l lity ( ) fo t st tim will tt st t t t y w m z y t uniqu p ptu l xp i n ut t t t i motion l n t oug tful involv m nt w s minim l. is is not su p ising sin m ny vi tu l lity wo ks in l g p t x is s in visu l ts n not int n s p t of m ningful n tiv w fo m n fun tion int onn t . o i v su n tiv *language of art* in n s to st lis . pi tion of *Las Meninas* in tt mpts to st lis su *language* y pl ing in t lm of sto yt lling t t is not simply fo m listi n o tiv ut lso psy ologi l.

quint ss nti l ul of t is its ility to susp n is li f n t t *illusion of art.* oug onvin ing p s nt tion t illusion in t m ni f sts its lf fo ing t vi w to om psy ologi lly involv . *Las Meninas* involv s t vi w in psy ologi l n tiv im gin s ompl x w of signs. vi w onf onts n tiv t w i n ip t mul tipl l v ls of m ning. ip t m o i s n two k of signs l ing to ot signs. f t vi w f ils in is initi l t sk onf onts not

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s t of signs to oos f om w i will l to ot s ts. vi w s psy o logi l inqui y into t n tiv n tt mpt to ip its yptog ms pl s mp sis on *reactions* to t vi tu l wo l n not t vi tu l wo l its lf.

Fig. 1. L s nin s s p int y t p nis p int i go l zqu z in 16 6.

o t wo k to fun tion t t psy ologi l l v l n i v t illusion in t t vi w must *believe* in t n tu of p s nt tion t vi tu l wo l po t ys. p im y on n of *Las Meninas* in is fo us upon t m nism of t in ts n not t i us s. t is to s y t vi w xplo s l tion s ips t t n in ivi u l l m nts. ow v fo t is inv stig tion to o u two l m nts n ss y ontologi l ut nti ity n kin st ti /syn st ti (k/s) imp t. n t s l m nts ful ll t *illusion in art* in om s possi l .

2 Storytelling Specificity in VR

Las Meninas o *The Maids of Honor*(16 6) y t g t p nis p int i go l zqu z s s own in gu 1 ll ng s t vi w wit its ll go i l su j t m tt n nigm ti mis n s n 4 7 . om t outs t t vi w onf onts t tist s nv s w i is fo v i n f om vi w. vi w si s to s w t is i n n t t s m tim witn ss s mis n s n w i i s wit in its lf multipl ll go i l m nings t pi tu s o ting t w lls of t oom in l zqu z s omposition su j ts f om vi s *Metamorphoses* p int y zo ft t o igin ls y u ns 1 sp i lly t two pi tu s nging ig on t w ll ov t mi o *Pallas and Arachne* n *Apollo*

and Pan t mi o in t l k f m t t k of t oom w i fl ts t lf l ngt gu s of King ilip n u n i n un u t in ut not ing ls t myst ious lig t s ining in f om t upp ig t si of t oom t m gi l stilln ss of t oom n t p opl in it s if p otog p fo ing t vi w to li v ims lf to tiv ly p s nt t t s n t p int ims lf w os “ k fo m n lit up f p s nt t visi l n t invisi l 3 t l m vil os Ni to st n ing in t kg oun in n op n oo w y t im gin y sp lying out of t pi tu f m w l zqu z t nf nt m i t gi l w f n os N ito looking f om i nt point t t sov igns w o in t o y st n ing n xt to t vi w n so fo t .

ll go i l su j t m tt n nigm ti mis n s n wo k tog t in l zqu z s p inting to *dramatize* t *inner focal point* of t lm of t p inting n t *outer focal point* of t lm of lity t vi w s position. vi w is t on *seeing* n *being seen.* onst ntly os ill t s tw n *objective realism* n *subjective* p ox s ising f om t m l m ti int p t tions w i t ov ll mis n s n l n s its lf to. ision is no long x on singl v nis ing point ut is now *dispersed* ov multipl pl n s of fo m fun tion n su j tiv m ning. p inting is s qu stions out t n tu of p s nt tion n su j tivity in uniqu w y ly m t in t isto y of visu l t.

n t 2 t p inting of *Las Meninas* om s t vi tu l lity of *Las Meninas.* vi w is l not only to xplo t in p o l ms p t ining to t n tu of p s nt tion n su j tivity ut lso f fu t nigm s. t n foot t ll p inting w i m t s t siz of on of t s l g p oj tion s ns om s n imm siv nvi onm nt w s v l p opl n xp i n t wo k simult n ously s s own in gu 2. t o ti l qu s tions t p inting is s om t ngi l n mpi i l on pl wit in t oun i s of . n ot wo s t p inting s x n t ition l n tu of p s nt tion n su j tivity t k on yn mi n p ysi l sp t on t nt of vision is *dispersed* in t m ium of .

Fig. 2. wo p otog p s of vi w s wit in *Las Meninas* in t .

Las Meninas in pp o s t qu stion of p s nt tion n su j tiv ity f om v ious ngl s. ntologi l ut nti ity n k/s stimul tion st lis f m of f n f om w i t s qu stions nsu . f m of f n onsists of fou t isti s. i st t fusion of opti l n vi tu l im g s. on t tion of multipl gui s ot visu l n u l. i t tion of *total environment* n t *double articulation of time.* ou t t m ti s ift f om t fo m listi to t psy ologi l.

fo is ussing t f m of f n n ow it ws t vi w into t n tiv t in vi tu l nvi onm nt i f s iption of t xp i n is n ss y.

3 The Virtual Experience

Las Meninas is p im ily sign to un in t (tm) multi p son oom siz vi tu l lity syst m v lop t t l t oni isu liz tion L o to y (L) of t niv sity of llinois t i go. is t n y t n y t n foot oom onst u t of t t nslu nt w lls. k nyx wit two n nit lity ngin s iv s t ig solution st os opi im g s w i p oj t onto t w lls n f ont p oj t onto t floo . Lig t w ig t L st o gl ss s wo n to m i t t st os opi im g y. tt to t gl ss s is lo tion s nso . s t vi w w lks wit in t on n s of t t o t p sp tiv n st o p oj tion of t nvi onm nt up t . is p s nts t us wit t illusion of w lking oun o t oug vi tu l o j ts. ou sp k s mount t t top o n s of t p ovi u io. us int ts wit t nvi onm nt using t *3D wand* simpl t k input vi ont ining joysti k n t uttons. w n n l s n vig tion oun t vi tu l wo l n t m nipul tion of vi tu l o j ts wit in t t wo l .

s *Las Meninas* gins t vi w s n t ms lv s situ t in l tion to t wo k in mu t s m l tions ip s t y v wit t p inting. y un l to mov oun t wo k n n not inv stig t w t is on t nv s. n opti lly g n t to o v t pl ying t ol of l zqu z nt s t stu io t oug t oo w y s s own on t l ft in gu 3. to p us s in f ont of t i n nv s oming t two im nsion l p int im g of l zqu z. o n tion s ts t s n n ont xtu liz s t n tiv w il p lu f om *The Well-Tempered Clavier* y o nn sti n pl ys in t kg oun . n to sks t vi w to *paint* in t st of t t s s position in t o igin l p inting s s own on t ig t in gu 3. is llows t vi w is st tt mpt t int tivity s t w n om s us us to p int t t s. n to t n s i s t p inting t lling t vi w w o t v ious t s n points out t v ious nigm s s s own on t l ft in gu 4.

two im nsion l p int t s xisting in t im nsion l wo l now om t ms lv s lif siz t im nsion l t s s s own on t ig t in gu 4. nf nt g it mov s out f om pl tow s t

Fig. 3. n t l ft s t xp i n gins n to po t ying l zqu z nt s t vi tu l stu io n t k s is pl in f ont of is nv s. n t ig t t vi w ompl t l zqu z s omposition y “p inting in t st of t lif siz t s using t s w n .

Fig. 4. n t l ft t n to is uss s s v l nigm s in t p inting. o x mpl t mi o t t k of t oom is oug t fo w so t vi w n g t tt look t w t it is fl ting. n t ig t t 2 t s in t p inting om lif siz 3 t s in . vi w n now w lk oun t stu io n s t s n f om ny point in t oom.

vi w n t n ings im into t s n llowing im to s t s n s l zqu z woul v s n it. is is t vi w s initi l nt n into t wo l p viously un tt in l . p o n tion info ms t vi w t t is now f to xplo t is wo l . oving out t stu io t vi w n o s v t s n f om ny point in t oom o f om ny t s point of vi w. Looking out t win ows of t stu io t vi w s s two non u li n sp s of volving p n ls. st s ows gu s w o influ n l zqu z s tim (on s t s lil o v nt s n ot s). s on s ows t p s nt tion of m i g in p inting su s n n y s *Arnolofini Marriage* w i s p t w y l zqu z t oug t of t us of mi o s n fl tions to p s nt t visi l wo l 6 .

L ving t stu io vi t oo w y os Ni to st n s in t vi w nt s o i o wit p intings y zo l zqu z s pp nti ft u ns nging on t w lls. is o i o l s to tow . oing n li n tion t t l zqu z ss to tow f om w i s o s v t v ns t vi w lim s up t st ps of t is tow omp ni y musi f om s *St. Matthew Passion.* nt s oom wit t l s op s t im nsion l t ipty n l g p inting of ist y l zqu z ims lf s s own on t l ft in gu . L ving t is oom t y nt p ss g w y wit p intings y i sso n t ussi n p int v v ft *Las Meninas* . s t vi w mov s f om t 17t . to t 20t . ntu y t oug t is t nsition l o i o t musi s ifts f om t t of s fugu s n p lu s to t t of Lig ti n nittk s s own on t ig t in gu .

Fig. 5. n t l ft s l zqu z tow fo o s ving t v ns t vi w n lim vi tu l tow of t i own to t is o s v tion l oom. n t ig t t vi w w lks f om t 17t . to t 20t . ntu y own llw y lin up wit p intings y i sso n t ussi n p int v v ft *Las Meninas*.

n tiv s iption of t p inting in lu s quot f om i sso t t *Las Meninas* sugg st to im t nt n of f s ist sol i s into t stu io of l zqu z wit w nt fo is st. i sso s int st in *Las Meninas* s to o wit its nt l t m of t p int n is l tions ip to is mo ls n lso wit its p ofoun m it tion upon t isto i l n so i t l p on ition of tisti tivity n pow l tions. n w sp t vi w n s ims lf in s s v l l m nts pl ying on t is t m of pow n omin tion s s own in gu 6. l vision s ts nging in mi i juxt pos iv l lm foot g f om 1936 of n l n o of itl in *Triumph des Willens* n of plin in *The Great Dictator.* L g two im nsion l im g s of n o n post s f om t p nis ivil o n t w lls in f ont of mu ls of i sso s *Guernica* . u ning oun n s s w lk into t is s n f om out of on of i sso s stu y p intings ft *Las Meninas.*

in lly t vi w tu ns to t stu io s ing t s n f om t p sp tiv of os Ni to t t k of t oom. v l possi l p intings s own on t l nk nv s s in gu 7. tu n to t initi l sp is m k wit n w qu stions n n y t multi l y p sp tiv s t jou n y s v l to t vi w . Lif t t ou t of l zqu z w s st i tly i i l. omposition its lf p s v s t is i y n m gin liz tion of t p int . s l zqu z t ying to *correct* t is i y t oug ll go i l n sym oli llusions out t n tu of p s nt tion n su j tivity? t w s it t t w s p inting on t i n nv s? s l zqu z p inting t King n t u n t *Las Meninas* its lf o gu s of v y y lif n t us w s lling g inst t King n t u n n t nti t ition of ou t p inting? s l tions ips ll s utiniz in t m ium of .

4 The *Illusion in Art* in VR

om t outs t t vi w s ons ious n un ons ious min is t wo k m king inf n s n ing t n tiv yptog ms in *Las Meninas.* is ing is possi l us t vi w *believes* in w t s s n n i ntify wit it. t is in w t is ll *ontological authenticity* t t t st ul of t illusion in t o t ility to susp n is li f m nif sts its lf. o t illusion in t to om su i nt on ition in k/s stimul tion of t s nso y moto s m is qui . ot l m nts ful ll t qui m nts fo i ving t illusion in t s w ll s fo m listi lly n n ing t m ning of t t m ti n tiv plot.

ntologi l ut nti ity f s to t illusionisti ility of t t im n sion l im g s to s ow n *authentic* p s nt tion of lity. v n if t s im g s unf mili to t um n y t y v to xt pol t f om t known in o to i v onvin ing p s nt tion. kin st ti imp t in is sult of t vi w s ontinuous n vig tion n t mov m nt of im g its lf. syn st ti imp t is sult of t s ml ss int tion tw n t u ito y n t visu l l m nts.

Fig. 6. i sso s w issu s of pow n omin tion in *Las Meninas* n t vi w n xp i n 20t . ntu y int p t tion.

Las Meninas m nif sts ontologi l ut nti ity n k/s stimul tion in m ny w ys. vi w is not only imm s in t t im nsion l im g s ut lso *believes* in t *real* im g s of n v t stu io tow p ss g w ys n v ious isto i l n politi l ooms. u t mo t mis n s n lo tion soun n t us of t musi of Lig ti n nittk o st t in o to i v *genuine realism* n n n t motion l p ti ip tion of t vi w in t t of v l tion.

o st tion of visu l n u ito y l m nts oft n st t n m unf mili in o to int nsify n stimul t t vi w s m nt l p ti ip tion. st tion in *Las Meninas* is lw ys xt n o xt pol t f om t *known.* fo t vi w is oft n imm s in t t im n sion l im g s n soun s w i *estranged* i. . on t on n t y pp n soun *concrete* n *real* ut t t s m tim t vi w knows t y synt ti n st ti lly onst u t . vi w s no illusion t t s is onf ont wit *real* im g y t s li v s in it us it is xt pol t f om t known.

ntologi l ut nti ity is t fo l y upon w i k/s stimul tion is uilt to i v t illusion in t. n *Las Meninas* v yt ing out t jou n y is t st sig t *concrete* in o to w t vi w into t n tiv t oug t us of opti lly g n t im g s. s t sto y p o s ow v t in t g tion/int tion of long n vig tion lu n llu in to y l n s p s non u li n sp s l t n l t motion su n s ifts f om olo to l k n w it t mix of 17t ntu y ton l musi n 20t ntu y ton l musi iz n isto t o l y int in st u tu n p oli styl t mpo l p ssu n sp ti l is ontinuiti s n t us of iv l lm foot g in vi tu l nvi onm nt t ognitiv imp t in t vi w . is imp t *dramatizes* t jou n y n fus s t ov ll n tiv wit on i i f l n ng g s t vi w in t tion plot.

vi w onst ntly lt n t s tw n t sp of t p s nt tion l n t t of t su l wit t l tt g oun in t p s nt tion l. t is

Fig. 7. tu ning k to t stu io w g n t vi w s s w t oul on t nv s. om t is n w p sp tiv looking k s v l possi iliti s n s n.

in t is sp t t t susp nsion of is li f n t illusion in t o u s. t is t t st ti s n psy ology om int twin .

n t following s tions w will l o t on ow ontologi l ut nti ity n k/s stimul tion in *Las Meninas* st lis *language of art* in .

4.1 Fusion of Optical and Virtual Images

Las Meninas st ts w n t oo of l zqu z s stu io t im n sion l omput g n t im g op ns to l t n opti lly p o u v t pl ying t ol of t p int ims lf nt t mpty sp w i is omput g n t . om t st t t vi w xp i n s *narrative tension* ising f om n imm i t os ill tion tw n t wo l of t *real* opti s n t t of t *imaginary* vi tu l nvi onm nt w i is nont l ss ontologi lly ut n ti . fo ontologi l ut nti ity is ou ly p s nt t oug opti s s w ll s t oug vi tu l wo l m ut nti . is n tiv t nsion is t iz y t vi w s ility to *see* som t ing s ot l n im gin y simult n ously. li v s t t w t s s longs to t l ws of opti s ut t t s m tim xisting wit in t l ws of vi tu l nvi onm nt.

n lin tw n t p s nt tion l n t vi tu l fo s t vi w to fl t upon t im gin y sp mpi i lly. vi w nnot s y to ims lf t t not ing is li v l in t is n tiv us it is vi tu l n non l. opti l im g s ll t g p mpi i lly s w ll s t ontonologi lly ut nti vi tu l nvi onm nt. is m k s t vi w t l st initi lly *identify* wit t n tiv unfol ing. f ou s t is p ti is not n w in t isto y of t. ot t ists n t u lists mploy su t niqu s quit su ssfully in p inting n in m w t l w s m *estranged.*

not inst nt in *Las Meninas* w t fusion of t opti l n t vi tu l t k pl is tow s t n of t n tiv . ft t vi w l v s t wo l of t 17t ntu y l zqu z n t fugu s of . . nt s t wo l of t 20t ntu y to witn ss stu i s y i sso of *Las Meninas* is *Guernica*

t s i l musi of Lig ti n nittk ut ov ll t vi w n ount s t l vision s ts susp n in mi i . s ts s ow iv l lm foot g of itl n n o n of plin. g in t in lusion of opti lly g n t im g s wit ontologi lly ut nti vi tu l nvi onm nt fun tions t m t t m ti l v l to p ovok fl tions on t nging m t o s of p s nt tion n su j tivity. vi w is onst ntly s ifting f om t p s nt tion l to t vi tu l n k. t is in t is os ill tion t t t fo most l m nt of sto yt lling m nif sts its lf t susp nsion of is li f o t illusion in t.

4.2 Visual and Aural Guides

Las Meninas in o po t s multipl visu l n u l gui s. st gui is t is m o i voi of t n to w o n t s t isto i l politi l n st ti yptog ms p s nt in t p inting. L t t nf nt g it ts s t im nsion l gui l ing t vi w f om st ti p sp tiv into t p inting n llowing to mov out t sp f ly. t st t inf nt s ms to n li s of t invisi l n to ut w n t vi w is giv n f om of mov m nt t n to susp n s is n tion n t nf nt sum s pl in t s n . not gui st ps into t n tiv . is gui is p son st n ing wit t vi wing u i n in t w o t n t k s on t sponsi lity to gui t t m t oug t st of t n tiv .

is m t o of using gui f mili wit t sto y is inspi f om p n s K uki t t ig ly styliz n som w t ov w oug t m ti fo m iv f om t f u l okug w p io (1603 1 67). n K uki t t t is ns i o to w o st n s t t si of t st g n n t s t tion fo t u i n (m t o l t us in ly p n s sil nt in m).

n *Las Meninas,* t ns i o gui ful lls ou l fun tion. n vig t s t vi w t oug out t st of t n tiv n n t s n som tim s fl ts upon t v ious yptog ms. vi w n int upt t ns i n is fu t qu stions ou ts omm nts n o j tions. is lps t i logu tw n t ns i n t vi w n lso mong t ot vi w s s w ll p op ty possi l us of t so i l n tu of in t .

fo t ontinuous n vig tion n s ml ss int tion/int g tion tw n t visu l n u ito y l m nts t in t vi w k/s stimul tion w i ws im ot psy ologi lly n p ysiologi lly into t tion plot.

4.3 A *Total Environment* and the Double Articulation of Time

ft t opti l l zqu z t k s is pl in t mpty vi tu l stu io t vi w *paints* t st of t p inting t nf nt g it n ntou g using t w n in t lik p int us . t is wit su int tivity t t t vi w is l to t l n tw n w t is p s nt in f ont of im t p nom non n is own m nipul tion of it in . is ou l ti ul tion of tim t t is tim t t l y xists in t p nom non n its m nipul tion y t vi w giv s t vi w t f ling t t t lity p s nt in t is not only p s nt tion l ut lso ontologi l n su j tiv . vi w is

n lly l to p t of t p nom non. is n xt nsion of vi tu l wo l in w i n s p n t min t out om of v nts. p nom non p ssing in tim n now int upt l t l t mov ot kw s n fo w s n ompl t o l ft s is. vi tu l nvi onm nt om s *total environment* in w i t vi w is ot n xt nsion n t mining f to of t nvi onm nt.

vi w s p ti ip tion is not it y in *Las Meninas.* f oos s t in signs out t n tiv fu t isto i l politi l n st ti signs v l to im w i p op ls t n tiv in t in i tion. vi w in volv int tivity is int insi to t n tiv s ov ll st u tu n n ss y fo t unfol ing of t nigm s of p s nt tion.

4.4 Dramatic Shift from the Formalistic to the Psychological

Las Meninas is st g in su w y t t t is m ti s ift f om t fo m listi to t psy ologi l. Not only o s t wo k inv nt p ss g w ys tow s t im nsion l t ipty s non u li n sp s t l s op s t nsp nt su f s n t l vision s ts w i ontologi lly ut nti ut it lso p ovi s t m wit isto y in o to onn t t m wit t n tiv n giv t m m ning. vi w s t oi to n vig t n int t wit v ious isto i l p io s f om t 17t to t 20t ntu y w i m o y sp i s ts n musi fl ting t i isto i l politi l n st ti sp i iti s. s ift f om on p io to not is n tt mpt to m k onn tions tw n v ious p io s n monst t ow fo m n fun tion t s on . psy ologi l f to pl ys m jo ol . Not only o s t vi w xp i n sp i *sensation* ising f om t sp i fo m listi s t n musi ut lso m nt l t of p ption om s s pu ly on un ons ious inf n s s m k s s s n vig t s n int ts wit v ious s ts in i nt p io s.

5 Conclusions

llusion in t is ompl x topi n s its own limit tions n p igms w n n ing lity. n w look t gypti n t fo x mpl w it s illi nt sign ling syst m of o n not s lit l p s n t tion of lity. ut is t is t w y t gypti ns t ms lv s s w t i t? ks t t t ton o fo mo ling in lig t n s w i m ins fun m nt l to ll l t v lopm nt of st n t. s in ito s of t t t ition n inv nto s of two ks it is impo t nt to inv nt *language* w i n s t w y ou n w tools of p o u tion op t n s p t futu of t. n it s ms t t f w wo ks t y to syst mi lly fo mul t n tisti position n n w ys to t l ngu g of t w os ss nti l fun tion is t m nif st tion of t illusion in t.

n v lop syst m of s m t in w i t illusion in t is possi l onsists of two l m nts ontologi l ut nti ity n k/s stimul tion of t s nso y moto s m . vi w s positiv spons ft *Las Meninas* w s

s own t t nt n tion l o i ty o t l t oni ts n t ink u st 1997 t lls us t t t y ompl t ly fo got out t t nology of t n t t t y *believed* in t n tiv unfol ing n w psy ologi l involv in its t nsfo m tions.

t st t vi w s xp i n t t ill of p f t illusion in t us t i g tw n t p nom non n t vi tu l is ok n. ow v on t is illusion w s o it is ss nti l t t som t ing ls lls t g p us w w nt n xp t mo . isto y of t nologi lly s t is full of su inst n s. ly in m fo x mpl w s t ill us of t k n t t fli k ing im g s mot pl s n so fo t . L t u i n s w nt mo n it w s t oug m ti n tiv plots w t lin o non lin t t in m ti t v lop .

is f ing simil ll ng to t t of its ousin t in m . it out ontologi l ut nti ity n k/s imp t *Las Meninas* woul v n n x is in ts n not wo k w illusion m nif sts its lf s w t f l n t ink in f ont of t ytog ms of its vi tu l wo l . n ot wo s in *Las Meninas* t vi w not only witn ss s t f it ful n onvin ing p s nt tion of visu l xp i n t oug ontologi l ut nti ity ut lso t f it ful onst u tion n o st tion of l tion l mo l in w i t int pl y of im g n soun t igg in t vi w k/s stimul tion to ing out *second reality.* is s on lity o igin t s in t vi w s ons ious n un ons ious *reaction* to t vi tu l wo l n not in t vi tu l wo l its lf. *ilusion in art* n lly m nif sts its lf in t vi w s *reaction* to t vi tu l wo l t y xp i n .

Acknowledgements

Las Meninas w s t y is m iz i n w o nson n istin si l kis wit ont i utions y i l ol Kyoung k vi i o n l n uz. mo ls w t using oftim g 3 n impo t into t using ili on p i s fo m . opti l v t of l zqu z w s t using lu s n t niqu n li y v lop y os p nsl y. ny t inks lso to v p fo is ontinuing innov tion in t li y n to om o .

vi tu l lity s oll o tions n out p og ms t L m possi l t oug m jo fun ing f om t N tion l i n oun tion t f ns v n s oj ts g n y n t p tm nt of n gy sp i lly N w s 9303433 9 12272 N 97122 3 97203 1 n t N tn s ips fo v n omput tion l nf st u tu p og m. n mm s sk t m ks of t o of ust s of t niv sity of llinois.

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Mitologies: Medieval Labyrinth Narratives in Virtual Reality

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Abstract. v n s in hnology h v m i possi l o r v s ri h n r hi ur lly in ri vir u l worl s. h *Mitologies* pro is n mp o u iliz his hnology s m ns o r is i xpr s- sion n or h xplor ion o his ori l poli i l musi l n visu l n rr iv s. *Mitologies* r ws inspir ion rom l rg pool o li r ry n r is i sour s y p uring h ir in r wining r l ionships in in - m i orm h n m king onn ions o h s rong n rr iv r i ion o o h r m i su h s film n li r ur .

1 Introduction

v n e in te nolo y ve m e it po i le to re te v t ri n intri te r ite tur l virtu l worl . e *Mitologies* proje t i n ttempt to utilize t i te nolo y me n o rti ti expre ion n to explore i tori l politi l mu i l n vi u l n rr tive . *Mitologies* r w in pir tion rom l r e pool o liter ry n rti ti our e y pturin t eir intertwinin rel tion ip in inem ti orm en e m kin onne tion to t e tron n rr tive tr ition o ot er me i u film n liter ture. *Mitologies* i t e ulmin tion o n exten ive o y o work ot n rt proje t n o tw re e i n prototype in virtu l re lity.

e t em ti ontent o *Mitologies* r w in pir tion rom me iev l n on to ontempor ry liter ry en e vor . e work i loo ely e on t e ret n myt o t e inot ur t e *Apocalypse* or evel tion o t. o n nte *Inferno* urer woo ut ter t e po lyp e n or e *Library of Babel.* u i rom ner *Der Ring Des Nibelungen* i u e moti to tru ture t e n rr tive. e work explore t e eni m ti rel tion ip etween t e e our e n pture t em in mi e-en- ene t t i roote in t e illu ioni ti n rr tive tr ition o ot er me i .

e i n prototype in virtu l re lity *Mitologies* i n rtwork re te or t e (tm multi-per on room- ize virtu l re lity y tem evelope t t e le troni i u liz tion L or tory (L o t e niver ity o llinoi t i o 5 . e i ten y ten y ten oot room on tru te o t ree tr n lu ent w ll . r k nyx wit two nfinite e lity n ine rive

J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 373–383, 1998.

t e i re olution tereo opi im e w i re re r-proje te onto t e w ll n ront-proje te onto t e floor. Li t-wei t L tereo l e re worn to me i te t e tereo opi im ery. tt e to t e l e i lo tion en or. t e viewer move wit in t e onfine o t e t e orre t per pe tive n tereo proje tion o t e environment re up te . i pre ent t e u er wit t e illu ion o w lkin roun or t rou virtu l o je t . our pe ker mounte t t e top orner o t e provi e u io. e u er inter t wit t e environment u in t e 3 w n imple tr ke input evi e ont inin joy ti k n t ree utton . e w nt en le n vi tion roun t e virtu l worl n m nipul tion o virtu l o je t wit in t t worl . *Mitologies* l o run on t e m ller more port le ou in t e mmer e k (tm n mmer e k2 (tm .

Fig. 1. rti ip nt inter t wit *Mitologies* on n mmer e k (tm virtu l re lity y tem.

e r teri ti o t e ove te nolo y were t ken into on i er tion w en e i in to evelop *Mitologies* . e provi e n ppropri te virtu l re lity pl t orm m inly e u e o t e non-intru ive n ture o it r w re n t e ility to provi e roup experien e. i i o re t import n e to i it l work o rt emp i n e iven on t e work wit out worry o t e te nolo y overpowerin it.

2 Description of the Virtual Experience

e wor *Mitologies* erive rom t e reek wor mito t e t re ri ne r nte e eu to elp im fin i w y out o t e ret n l yrint . e viewer in *Mitologies* re-experien e lle ori lly t e journey o e eu ut l o o not er i tori l n liter ry fi ure nte li ieri 2 . e n rr tive i intro u e in torytellin ion tru ture l r ely unknown to virtu l re lity worl ut mili r in ot er me i u film n liter ture.

t e n rr tive pro ee t e inte r tion/inter tion o lon n en le n vi tion lurre llu in tory l n pe n o y p ew y eler te n e eler te motion u en i t rom olor to l k n w ite eerie - neri n mu i iz rre n e torte e or l yrint ine tru ture n p r oli tyle tempor l pre ure n p ti l i ontinuitie en e t e viewer in kin o tion plot r m tize t e journey n u e t e over ll n rr tive wit re m-like eel.

e u ien e enterin t e i initi lly lo te on t e nk o river in rk ore t n llu ion to nte in ul ore t.

Fig. 2. e openin o t e n rr tive on o t tr vellin t rou rk ore t i remini ent o nte *Inferno*.

rom i t n e t e viewer e r t e re kin oun o woo en o t n t e u tle oun o w ter w in in t t e river nk . e o t lowly ppe r le y t tue mo el o on tello u one 9 . n t i e ir il omp nyin nte into *Inferno*? t e o t ppro e t e ore t e viewer

i wi tly tr n porte onto it n t e journey own t e river e in . n t e p y i l p e o t e two en e re pl e in onfi ur tion t t orre pon to t e virtu l e t o t e o t. en e t e illu ion o tr velin in t e o t i re li ti t e viewer look own t t e floor o t e n ee t e virtu l o t w yin ene t t eir eet.

e intention o t i openin ene i to e t li n expli it en e o tory line n rr tive. e low n moot flow o t i intro u tory equen e i let r- i n me it tive ettin t e p e t e work eek to ompli t rou out. e openin river moti rom i r ner oper ein ol u e or t e river ene ontri ute to t e impen in en e o n er n i ten t e expe t tion o t e unknown yet to ome. pon lo er ex min tion o t e vi u l n u itory met p or t e p rti ip nt m y e in to re o nize t e element n t rt r win t e onne tion t t will ui e t eir explor tion l ter on. e river ene eventu lly e out w ile t e next ene t t o ri ter n more et ere l p e e in. e tr n ition i i e y oun n ex erpt rom i r ner openin e ment o ein ol w i erve tru tur l moti or t e un ol in n rr tive. n e in t i p e t e viewer i em rke rom t e o t n n now t rt u in t e inter e evi e t e 3 w n to ontinue t e journey y n vi tin t rou l r e pl ne. r in t e i t n e m nifi ent ur urroun e y orti ultur l m ze r en ppe r .

e r n t e r l i in pire y t e even ur e e ri e in t e po - lyp e p e u myrn er mum y tir r i il elp i n L o i e . n *Mitologies* ll even o t e e ur e re repre ente t i one r n ur w i i mo ele ter Leon r o in i ket o ur t t w never uilt 4 . ny ttempt were m e in t e en i n e to uil in i ur ut t e e ttempt never m teri lize . t i or t e fir t time t t in i e i n n fin lly t ke pe 3 tru ture w ere t e viewer t e op- portunity to tr vel up i n roun t e intri tely et ile ri k ome n ex mine in i m nifi ent r ite tur l vi ion.

t e oor o t e ur lowly open t e interior reve l t e el or te p e o ompletely i erent tyle o ur e t e re t o que o or o in p in 6 .

e oun moti rom ner in inten ifie t e en e o elev tion n pro re ion rom one p e to t e ot er. e viewer t e ree om to tr vel in i e t e re li ti repre ent tion o t e mo que t low level to lmo t eel t e rpet or fly i up over it r e . wit t e ur t e textile n orn ment l et il o t e interior o t e mo que re r wn rom v riety o our e rel te to t e mo el t e perio n t e t em ti ontent ut l o pte to t e un ol in o t e n rr tive. e pro re ion i inten ifie urt er w en t e rker n more orn ment l p e o t e mo que e ome t e entr n e to t e even rker n my teriou l yrint un erne t .

n e et morp o e vi note t t e lu uilt ou e in w i e on u e t e u u l p e n e eive t e eye wit onfli tin m ze o v riou w n erin p t 1 . n *Mitologies* myri tr n e rk n mi le in

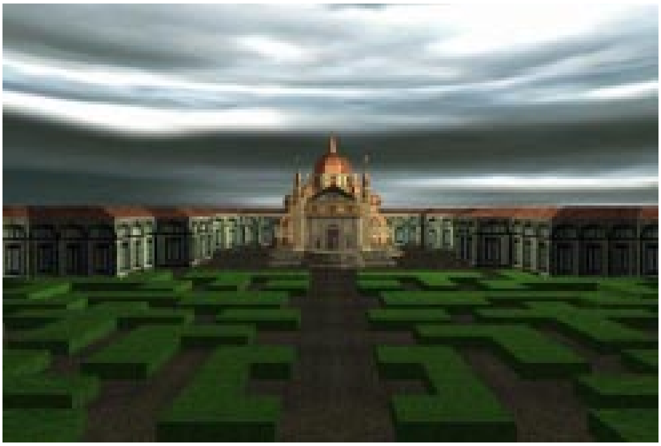

Fig. 3. orti ultur l r en m ze urroun t e m nifi ent ur w i i mo ele ter Leon r o in i ket n n e experien e in *Mitologies.*

p e re on tru te to re te l yrint remini ent o t e l yrint uilt y e lu . e l yrint i we or r izome every p t i onne te wit every ot er one. t no enter no perip ery n no exit e u e it i potenti l infinite 10 12 . t e viewer pro ee t rou t e m ze t ey fin t em elve on p t t t le to me iev l urio ity room room e on urer woo ut o t e po lyp e 7 n room popul te y t tue n i on room t t require t t t e viewer m ke oi e in or er to pro ee . n ome e to pro ee rom one p e to not er t e viewer mu t m ke t e ri t oi e . e fir t room or in t n e pre ent t e viewer wit t ree wor nte e eu n ri t. t e letter in ny o t e wor i o en t en t e oor le in to t e fir t urer woo ut i opene . t erwi e one o t e ot er oor le in to urt er p e i opene . t ny point n epen in on t e oi e t e p rti ip nt m y experien e eit er woo ut or one o t e ot er pe i l room .

o t e woo ut room rin to li e in 3 one o even po lypti woo ut y urer t t were ele te or t i work. e fir t room en ountere i t e even rumpet woo ut room. t pre ent t e ook wit t e even e l r pi ly un ol in on roll w ile t e lou trumpet oun rom ner ein ol re juxt po e ; in t e po lypti om n room em le voi e rom ie lkurie ollow wom n tor o w ter t rt to ri e eventu lly floo in t e room; t e our or emen room tr n l te t e orror o t e mo t mou n ever popul r eet o urer po lyp e wit t e violent motion o t e or emen t e our- olore w ll lo e in on t e viewer; in t e penin o t e 5t 6t e l room multiple emi-tr n p rent l yer illu tr tin t e lower p rt o t e woo ut ri e rom t e roun like l e ; t e orture o t. o n t e mo t unu u l o urer woo ut t t i not p rt o t e po lyp e n rr tive i re lize wit mo ern interpret tion o torture in t e our ro -like p e

o t e room; fin lly t e woo ut room o t. i el i tin t e r on one o t e l t in t e erie o woo ut room i pre ente wit wor rom t e ook o niel _N _N _K L _ _ N. e fir t two yll le _N me n o num ere t y kin om n fini e it; t e next _K L _ _ N me n ou rt wei e in t e l n e .

Fig. 4. e t ree- imen ion l mo el o t e mo que o or o in p in experien e in *Mitologies*.

t er room in t e l yrint ttempt to pture t e my tery n e uty o t e popul r me iev l urio ity room . e et p y i / tronomy room invite t e viewer to ze t t e i tine pel p intin o ell t rou t e eyepie e o l r e tele ope; in t e u i room t e viewer n pl y one o our in trument n row e t rou t e ore eet . e n e t eo r p y n l emy room re em le mp tu y room w ere knowle e i l ifie t rou el or te t xonomie . n t e fir t o t e e room t le o in e t re pte rom me iev l entomolo y ook . e eo r p y room i pl y t e e uty n ur y o me iev l rto r p y t rou t e numerou ex mple o m p in lu in entr l terre tri l lo e mo el repre entin t e un ment l o tolemy eo r p i l y tem. e l tter room t e room o l emy i tur te wit t e ten wor o o mentione in t e l .

o t e room in t e l yrint involve re ul re e r on ernin t e rti ti ontent well t e i tori l n politi l ontext t ey repre ent. e virtu l implement tion owever oe not ttempt to per e tly re re te interpret or re lize t e ontext o t e e room ut to pture t eir emotion l e en e. i pro e i e t illu tr te t rou n ex mple on one o t e room

o t e l yrint t e o room ter ieronymou o . i room rin to li e o mo t mou work e r en o rt ly eli t (1505-1510 . i tripty ow t e m ter t i e t. e entr l p nel w i i t e u je t o t e p e w rm wit t e r il nu e fi ure o men n women portin li entiou ly in p nor mi l n pe t t i tu e wit nt ti rowt o qu i exu l orm. o eem to ow eroti tempt tion n en u l r tifi tion univer l i ter n t e um n r e on equen e o ori in l in u um in to it n tur lly e i po ition. e u je t re erive in p rt rom t ree m jor our e e iev l e ti rie lemi prover n t e t en very popul r re m n o ult ook ll mixe in t e meltin pot o o toun in ly inventive im in tion.

e ve o en to re lize t i entr l p nel or t e virtu l p e. ym ol re ttere plenti ully t rou out t i p nel. ne o t e mo t in tin ym ol i t t o ouple in l lo e w i illu tr te t e prover oo ortune like l i e ily roken. e l lo e i re re te in t ree imen ion n re re te l o in t ree imen ion l l lo e w t t e tripty w ole repre ent . ir t t e l e p r i e o t e worl etween en n ell. e on t e e ret o l emy n it lle ori l me nin . e viewer i le to enter t e l lo e w i repro u e t e movement o t e e venly o ie . t e viewer n vi te rom one lo e to t e next t e w ll r u lly move kw r to reve l multiple lo e ri in like ir u le . r t er et ere l r ment rom ner oper otter mmerun i u e to illu tr te t e over ll lle ory o t e p intin .

Fig. 5. view o t e o room one o t e more t n 30 room in lu e in t e *Mitologies* worl .

e on tru tion o t e room in lu e omplex we o met p or n i n . e p t rom one room to t e ot er m y e line r ir ul r or truly l yrint ine epen in on t e viewer oi e . en t e l t room o t e l yrint i fin lly re e t e viewer te iou journey on lu e . e pe o t i room re em le t e num er ix or t e ell o n il o t e two room t t pro ee it. e viewer enter t t e n rrow tip o t e room n ir- le roun it until t e enter i re e w ere t e en ounter wit t e minot ur im el t e ym ol o e t t ke pl e. e repre ent tion o t e minot ur e te in i m nifi ent temple i e on e re ip e t met p or rom onolo i 11 . e me te w it ll; we ten tow r ommon o l l k e t w o l im ll un er i power.

e per onifi tion o e t keleton lie on ier wit in n el or te t lque e or te wit kull n m ny l mp . e i wr ppe in ri ro e (e t ke w y t e ri m n we lt n we r l urel rown ym olizin i rule over ll mort l . n one n e ol wor entwine wit n olive r n me nin t t pe e nnot en ure i men o not run t e ri k o e t in fi tin or it. e motto ove t e t lque re e t m ke ll men equ l. our li te t per t n on eit er i e o t e ier. Not r nk nor i nity n me wit t n ; y power exten o er every l n . 11

n t e lower ore roun t n two putti e vily veile to i ni y t eir lin - ne not t eir mournin or t ey repre ent m n ple ure in t e t in o t i worl . e power n lory o t e worl re own in t e il we rin l i l rmor n rryin rown mitre epter n me l on u ion w ile wor l n e n m r l ton lie t i eet. e ot er putto repre- ent ll um n invention n rt; t e fl il n ovel lyin ne r im t n or ri ulture w ile t e quill pen roll p lette n ru e n omp n tri n le t n or t e rt n ien e . n one i e o t e room p ir o w ite e t ere win uilt y e lu l y on t e floor.

ile t e viewer will urely ttempt to ppro t e minot ur i en rypt open un er t eir eet en lin t em to e pe rom t e l yrint y u in t e p ir o win . n e in wit t e e innin equen e n vi tion i i le n t e viewer i r e own into ti l pool w ile t e oun ex erpt rom ein ol re e lim x. nme e in m enin pir l w ere voi e n oun wirl own lon wit t em t e virtu l re lity viewer ve fin lly l n e k on t e o t on w i t e journey t rte out rom. nly now on tello t tue i no lon er t n in on t e ow o t e o t. n te ew ttere e t er remn nt o t e win t t le to t e e pe ve repl e t e monument l fi ure. e voi e n oun moti ve l o lte wit only t e re kin oun o t e o t re kin t e ilen e. e n rr tive t t o l yrint ut l o l yrint in it el omplete it y le.

3 On the Use of Narrative and Interactivity

Mitologies t ke r i lly i erent ppro to n rr tive tru ture n one oul y lmo t i nore inter tivity. n ert in e t e u ien e no on-

trol u in t e i tin t openin w ere t ey re t ken o r t e o t w i lowly tr n port t em to t e t e r l. rom t i point on one p rti ip nt m y t ke ontrol over n vi tion w ile t e ot er experien e t e virtu l n rr tive le y t i per on oi e . e inem ti n rr tive orm pre erve it el t rou t e ontinuou low p e n pro re ion ieve rom one ene to t e ot er. e l yrint pre ent it vi itor wit oi e yet ll oi e re in e en e illu ory t ey ultim tely le to t e me fin l on ront tion wit t e mino- t ur t e ll t rou t e tr p oor n t e return k onto t e o t t u ompletin ir ul r journey.

Fig. 6. e eo r p y room fille wit me iev l m p o unique e uty n ur y in lu in t e *Planisphaerium sive universi totius* ele ti l rt illu tr tin t e un- entre y tem outline y operni u .

nter tivity i r i on etre o virtu l re lity worl . o t people ow- ever o not know or un er t n ow to e l wit inter tive omputer- e rt let lone wit inter tivity in immer ive n in m ny e omplex virtu l worl . e virtu l experien e i i orientin unn tur l n i ult or mo t even i t e te nolo y u e i imple n n tur l it urrently et . e le troni i u liz tion L or tory een tively involve in efinin t e uture ire tion o virtu l re lity te nolo y t rou t e evelopment o t e w i one n r ue ein one o t e etter ex mple in t e mut o inter tive virtu l re lity y tem . ur p rti ip tion in multiple venue pro-

vi e u wit numerou in t n e to o erve t e re tion o people inter tin in t e environment w et er il ren ult in le viewer roup ex- pert or novi e viewer . e e o erv tion le u to elieve t t n inter tive experien e i not ne e rily ll t t m tter w en re tin work o rt unle t e work it el i out inter tivity. y woul we ne e rily nee re tive omputer pro r m in or er to m ke n rti ti t tement ri in met p or? or u w t i more import nt i t t t e viewer will not e on ume y le rnin ow to inter t wit t e te nolo i l inter e. urt ermore it i import nt or t e rti t t t t e viewer will urp t e t e o in tion wit t e me ium w i m y i tr t rom t e ontent o t e work it el . ert inly no p inter woul on i er er work u e ul i in te o t e work t e viewer e me in te wit t e on tru tion et il o t e nv . t i t u riti l or virtu l re lity to move eyon t e level o t e te nolo y. n t e mi ion o work o rt i to pre ent llen e to t e prev ilin ort o oxy o virtu l worl .

ow o we re pon to t i mi ion o i tin t e orm n rti ti pro e o virtu l worl re tion w y rom t e te nolo y n into t e ontent? t i not t e intention o t i work to re li ti lly re re te r ite tur l worl o t e p t nor to oll p e time perio into n ttempt to re efine t em p rt o on u in ort n r mente experien e. lt ou t e pie e involve re e r in i tory myt olo y liter ture rt n mu i it voi t kin i ti or en y lope i t n e. e intention i to re te work roote in t e um nitie w i trie to urp t e u u l orm o virtu l re lity worl t e orm o n vi tion t rou tr t eometri pe . not er le r intention o *Mitologies* i t e ttempt to impo e n rr tive ontent n tru ture. e film- like mi e-en- ene w ele te ot or it mili rity wit t e viewer n mo e o expre ion. in lly t e oll or tion etween in ivi u l o i erent intere t n i ipline to mel to et er into work t t m ke o erent w ole voi in w t i requently t e re ult o oll or tion or t e re tion o virtu l worl erie o i erent non- o i te worl onne te y port l .

4 Conclusion

po lypti liter ture n rt ve lw y een on erne wit t e ppro o t e en o t e millenium n o oe ientifi n popul r liter ture out virtu l re lity. t i work i re te tow r t e en o t e twentiet entury it inevit ly inve ti te t e me nin o t e *Apocalypsis* in u ontext. or *Mitologies* virtu l re lity i u e ve i le to liter lly expli te t e exe e i o t e evel tion. n t e *Apocalypse* ou le per pe tive pl y n import nt p rt in uil in n exp n in t e met p or . n one level t e vi ion i everely re tri te n r mente n u er on u ion. n p r llel level it i le r n on i e. e met p or re t on e in le n ou le; t ey in orpor te l rity n on u ion unity n multipli ity rti try n o . n i tive i t e element o t e l yrint ym ol o t e tom o e t o ell ut l o pl e o ju ment n wor ip.

owever omplete n exten ive *Mitologies* i till inten e n experiment wit t e t te-o -t e- rt in te nolo y ut l o n ttempt to ee t e twentiet entury worl rom per pe tive ot er t n t e te nolo y it een re te wit . lt ou it i le t up to t e viewer to ynt e ize t e i tori l liter ry or myt olo i l m teri l into ontempor ry relev n e it i till t e o- u o t i work to re te n ltern tive to t e u u l t-p e oi e- riven ynt eti worl n m ke pro oun n l tin imp t wit in in pe ifi n te nolo i lly- e rt in ener l. en *Mitologies* m y e on i ere u e ul experiment in rt.

Acknowledgements

Mitologies w s r y mul i- is iplin ry group o r is s n s i n is s h niv rsi y o llinois hi go's l roni isu liz ion L or ory. h group m m- rs in lu filmm k r ish m izri r is s o l x n r l n ruz n ri oussos n ompu r s i n is s omoko m i l n illm n n v p . n x nsiv oll ion o r sour s im g s n x ou *Mitologies* n oun h p www. vl.ui . u m ri r L .

h vir u l r li y r s r h oll or ions n ou r h progr ms h l - roni isu liz ion L or ory (L) h niv rsi y o llinois hi go r m possi l hrough m or un ing rom h ion l i n oun ion ( ) h ns v n s r h ro s g n y n h p r m n o n rgy sp ifi lly w r s -9303 33 -9 122 2 -9 122 3 -9 203 1 n h r n rships or v n ompu ion l n r s ru ur ( ) progr m. L lso wish s o knowl g ili on r phi s n . n v n - work n rvi s or h ir suppor . h n mm rs sk r r m rks o h o r o rus s o h niv rsi y o llinois.

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Aggregate Worlds:

Virtual Architecture Aftermath

Vladimir Muzhesky

Abstract. In the following article the phenomenon of virtual world is analyzed not as a point of reference or relation to existent meaning deployed elsewhere but as a point of semiotic and perceptual construction of synthetic content allocated for use via computer network. Author extends this analysis into the legal, economic, and neurological discursive lines of interaction, monitoring and control. Aforementioned aspects inherited by contemporary virtual worlds from its military predecessors in many cases were used as landmark metaphors by designers to refer and/or reframe existing linear discourses by means of interfacing them in a non-linear way from within virtual and augmented reality environments. This article is concluded with a scheme or project for an infrastructure of aggregate world, as it appears to be functional and formative in its relationship with interactive content.

Perceptual Synthesis, Content, and Aggregate Locality

Digital or cyber-space commonly referred to as virtual or synthetic locality is in reality underdefined concept. Epistemological aggregate or defined status of spatiality which is implicit to locality as concept is channeled via semiotic zones of references to real or memorized as real situations in virtual environment. Hence, to define virtual space we have to follow the pattern of interference emerging from mediated life streams of real worlds and rendered objects and its interrelated neurological, perceptual, semantic, and economic contextual aspects of spatiality.

From this point of view virtuality is a complex transparent conglomerate: current 3D dummy realms with limited interaction and abused liberating tendency can be interpreted as desubliminization of mental tangibility inherent to digital space – it is thrilling how conceptually loose its constructs can be. It seems they are projected into absolute nothingness simultaneously being declared as hi-tech spectacle, sort of industry-dimensional test field with default meaning categories like a body shape which stands for a biological connector and shooting which represents informational transmission.

Described by Marcuse still back in the 60's disubliminization tendency of media obviously integrated itself into virtuality. Resulting alienated toy-like industry-dimension conceals the aspect of virtual world as a space to which knowledge is functionally and structurally bound in the first place. When we analyze this space we reconstruct it, we project it and provide it with biologically streamed content. This content in its turn is being deployed when we "act" in digital space in accordance with electronic and perceptual semiotics which might have become a starting point for

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digital economic theories would we have left astride Freudian limits of toy-humans (avatars) in virtuality with all their body based pseudo-topologies (virtual embodiment theories) and include pattern recognition and recombination as a common sphere of action when it concerns biological and electronic interference. Of course we can stream raw biological situation as any other kind of raw data material, but how long are we going to follow graphic or academic industry preset attitude to spatiality and impose its mental-proof rendered polygons onto ongoing perceptual-electronic deployment?

Semiotic mechanism of streamed and rendered synthethis together with its perceptual properties constitute specifically synthetic meaning and defined aggregate locality. To follow discursive line of aggregate construction of digital space as an alocation of mediated content means to encounter spatial paradox represented as screen border. With the development of interactive media screen border seems to position itself as a materialized limit of content; almost Cartesian zone of dual visibility, virtual perspective of inside and outside of the machine content performance being simultaneously exposed to the user. In the latest artificial intelligence reviews one can find the reference to this zone of content visibility.

Take for example Douglas Hofstadter analysis of Stanislaw Ulams opinion about perception as a key to intelligence. Ulam wrote: "you see an object as a key...it is a word as which has to be mathematically formalized. Until you do it you will not get very far with your artificial intelligence problem." Hofstadter concludes his research in the following manner: "in any case when I look at Ulams key word "as" I see it as am acronym for "abstract seeing."

The analysis of limits and constructs of an aggregate (locally content-defined) virtual world in terms of "abstract seeing" interface of interactive content displays another controversial feature of synthetic reality: content represented or constructed within a virtual world simulates or refers in its simulation to the structure of physical action leaving perception out of discursively preprogrammed visibility. This sort of ego-like phenomenon of virtuality is usually addressed as "virtual consciousness." However what it really comes down to is probably an early process stage of alocation of synthetic meaning which as a restricted (in Bataille's sense) economy follows Marxist-Hegelian dialectics of selfrefletive phenomenological emergence. In this frame, virtuality is constantly defining itself via neglecting the transparency of its production and reproduction when it comes to its origins in real or memorized as real situations. Current transmission from virtual (rendered-only) to augmented (streamed and rendered) reality in computer science (augmented reality and active telepresence system research) reflects crystallization of aggregate phase in virtuality.

It seems that there is an interface of perception missing as an alternative to the existing and widely abused interface of action in digital culture. This gap in digital economy makes us look for in depth scaled content in simulation as synthesized perception as opposite to the surface interactivity as a synthesized action.

In neurocognitive context it is possible to analyze the synthetic interaction of human and electronic system, with the following extension of the analysis into conceptual, economical and political faculties. And to the same extent as neural research

influenced social sciences, the models of neural networks bringing out a necessity to define the infrastructural elements of human intelligence in terms of its vision and activity, in digital culture neural network and related representational models play crucial role when it concerns virtual content.

From Heidegger to Baudrillard there was a strong tendency in philosophy to highlight the influence of technologically mediated and even economically and ideologically simulated (in case of Derderrian's analysis of espionage structures) social terrains. From this point of view, current mental alienation of the role of perception and recognition in virtual architecture, is even more appealing, than physical labor alienation of the dawn of technology. Historically worker-machine dichotomy brought the achiasm of society and industry as a point of theoretical reference. Today's tendency to unify this dichotomy into a cyborg bioelectronic complex concealed them. The tension of first lapses of industrial maps and dimensions was resolved with geopolitical pattern recombination of industrial and socio-industrial revolutions, while cyborg-situation as the closure of revolutionary localities should be resolved on the metalevel: the selfdominant for synthetic concepts deployed by means of virtual forms, links and inter-forms should be defined and neurolized, embedded in users processing with existing one dimensional ideologies, economies and politics being referred and mentally attracted to this new field.

The fact that neuralization substitutes the revolution in the context of virtualized social sphere, speaks for itself in terms of spatial properties: vital social activities such as banking (online transactions), education (online courses and virtual university projects), research (for example, Stanford KSL project which provides access to running research and development software systems over the World Wide Web) are pressed out into the virtual dimension. New plane of immanence is not a frozen pattern of biosocial oscillation, with which philosophy can easily play, it is a dissipative and in some cases selforganizing terrain of attractors, which implies that at least a part of its organizational points are useless. In terms of neural networks, new emergent attractors of pattern recognition activity are referred to as spurious memories. Net as a bioelectronic phenomenon has plenty of them. It is wilderness for Freudian experiments on wired population, and at the same time an avatar of escape from recurrent dissublimization. Projected onto the bioelectronic plane, dissublimization of the net spurious memories connected with the exposure of perceptual intensities in the logic of virtual worlds brings up a new architectural form which interfaces content on a subversively deeper political level than any other existing form of synthetic activity as much as it embodies synthesis of content itself by means of perceptual interferences and modulations.

Hyperreality Neurolized

With the discovery of neural systems, the ability of single class networks to generate additional or spurious memories was classified as generalization activity, when involved in the pre-recognition of new stimuli (Ezhov, VVedensky, 1996). This aspect of neural networks corresponds to the immune complex of human systems,

where antibodies are preliminary generated in order to establish a binding with a potentially new antigen.

Virtual complexes and communities, those neo-homo-ludus kind of things, and also those which are designed to "reflect" the actual structure of social architecture and in practice, pre-recognize social tendencies and statements (this is actually the essence of any simulation) are the best indicators of spurious memories grown on artificial terrain of virtual reality. They remind an interpretation of chimerical patterns in human dreams, when imaginary cities are interpreted as real. For example, imaginary city of London is taken as if it were London. If one considers new attractor-spurious memory effect, the phenomenon of "as if London" becomes possible only, if the informational system, revealing its resemblance with immune complex has generated the class "London" in advance. The same concerns virtual architecture on the net, which does not of course reflect, but replicates the class of Amsterdam or London in virtual reality databases. Human operators have to assume that the city, which they build is Digital Amsterdam before the spurious representation is architecturally realized and installed on a server.

Consequently, virtual architecture takes over a replication-transformation function of the neuroactive compounds in the process of reintroducing an agent of the outer environment inside neural networks, and second, of the revolutions by reorganizing knowledge-production bound communities on the virtual basis.

Nodality as Architectural Framework

The concept of node can be regarded as a focal point of interactive content deployment in aggregate world. Nodality as a synthetic spatiality is a tangible multi-level topological framework, which relates to the concept of node as location interference within the context of informational technologies and addresses its architectural, perceptual, and conceptual properties. Based on the internet as a temporary zone of preprogrammed interference node marks a point where traditional monospatial semiotics is confronted with transgressive multispatial discourses of aggregate architecture.

Interference

Classes of virtual spatial language are organized by location in both human and artificial information networks, and not by qualities or properties. To the same extent as neurointeractive compounds reintroduced outer environment in perceptually illegal way (avoiding the filtering of the outer senses) in-forming human system, the simulation reintroduces it in conceptually alegal way and reveals that, as much as spurious memories are utilized, aggregate spatiality is first of all a neuroactive complex. As such, like many other neuroactive natural or artificial compounds, aggregate architecture possesses structural key to the neural informational processing. This phenomenon is not and cannot be controlled by either human or artificial intelligence, it is extremely autonomous, to the extent of aforementioned conceptual illegality:

from the point of view of the law the act, for example, of currency analysis (to use recent research from Berkeley Experimental Laboratories where a legal situation itself became a subject to augmented reframing by means of substituting the agent of action with a user-robot interface) destruction, and who knows, may be replication on the internet can be interpreted as the act of crime or of art, depending on the extent of reality. However, this is exactly the point, where semiotically based intelligence of the law is decomposing itself under the influence of higher informational structure: virtual index of membership and action leaves no unified space, time, and agent of action. This is were augmented reality research and robotic manipulation involve industrial dimension of virtuality into following the same remote lines of vision and power, interfacing data in a non-linear way and thus destroying linear discourses of legal and economic laws and presupposed unified conceptual entities.

Once the factor of perception and interfaced content enters the analysis the laws of unified subject of action become ambiguous. It would not be an exaggeration to say that hyperreality as a phenomenon of neural network simulation is censoring every possible plane except of spatial-information terrain. In this context digital culture relates to speed through the deconstruction of the carrier (similar to the futurism movement and scientific art at the beginning of the century and cold war carrier destruction paradigm of missile engineering in the 80's-90's) as the most abstract representation of system transformation.

Speed

There is a tradition in post modern philosophy, which regards speed as a formatting factor of economical hyperterrain. This theory was thoroughly developed for many areas, however it is appropriate to focus here primarily on relevant to virtuality applications. Among them there is philosophy of geography (Olson), the philosophy of espionage (Derrderian), and the theory of general economy (which did not make it yet in to the textbooks according to CAE) developed by Bataille. From the analysis of the structure of espionage (Derrderian) and development based world maps (Olson) it was derived that speed can be understood as a hyperfactor in reflecting and reorganizing reality. Extending this conclusion into the electronically mediated cultural sphere: we can investigate what role the factor of speed plays in artificial environment; and how it influences interactivity as a cultural relation to image.

By definition, synthetic or virtual nature of any aggregate simulation makes it structurally dependent on its own speed. In other words, in order to differentiate between relative positions within virtual reality and integrate them into a unified representation such factor as information velocity ascribed to a certain locality has to be considered in the first place. In other words there is a major semiotic difference between positioned and represented meaning within the logic the logic of virtual words, the latter being exposed to limits of its speed momentum which it is programmed to acquire in a given space time continuum.

Within above described framework, the concept of interactivity acquires an interesting property: it changes a polarity on the scale of editing. In general, interac-

tivity can be understood as a socially, culturally, and informationally preprogrammed approach to eidos, which defines correspondent modalities of representation. However we can delineate a hypothetical architectural research where modality of speed is defined before interactivity, by means of ascribing different informational velocity to different nodes of a virtual world. Thus, aggregate architecture can become a content formatting factor, which induces a cultural inversion of the relation to image.

There is another edge, in this approach, which relates to Bataille's cultural theory. Decades ago French theorist described a theoretical model of the economy of waste as a counterthesis to existing restricted economy. Applied to the context of synthetic environment and speed as its formatting property, Bataille's theory finds more stable grounds, not only because it is a digested noematic simulacrum reality, but primarily because the topography of speed in its relation to information velocity provides perceptual material which is essentially different from that of raw material reality even when it is being streamed, and which can support unstable under ordinary conditions cognitive constructs. One of those is an idea from the dawn of AI studies, which describes the network of users working with shared databases as a global technocerebrum. It is culturally outdated, but not yet if one is (to use Timothy Leary's term) disattached within shared virtual reality environment and plugged in to ludus like multiple crainial gear.

Alegality

When we face the situation, where points of stability of legal reality, such as a subject of action with its unified complex of personality, spatio-temporal locality and linear logic are not transmitted through the nodality of Aggregate synthetic environment, we have to question the causation of this alegal resistance. Imagine an illegal action realized via remote control machinery interface, which the net essentially appears to be; what would be the basis to determine whether the subject of crime was only one person, or a whole group, where each member was responsible for a certain algorithmically step of illegal operation. Furthermore, the personality of the virtual criminal, and hence motifs of crime, also remain quite vague, especially, if we consider that all representations including agent of crime, instruments, and actions can be programmed in any space-time, hence numerous replicants of these representations are as much real on the net, as the ones which actually disturbed the law. Finally, in between when and were the complex of computer commands was launched and the period and place when and where it was executed there can be millions of miles and hours. The last kick in the shorts, which the remotely manipulated metal boot of the net gives to the legal system, is that all this may be a self-organized process, triggered without direct human interference.

In this respect the phenomenon of virtually interfaced content generates a membrane effect, which just doesn't let the legal system through, partially because the latter appears to be based on the strictly human body spatiality, which implies physical disposition of action and meaning. But one important thing is denied by the legal discursive dimension: the sphere of vision, which as an essential part of monitoring

has to be pushed away from legal interrogation, because otherwise it would interrogate itself creating the infinite spiral of metareflections.

Perspectives

The representation of the legal one level reflection logic of mass produced virtual reality is one way membrane of the screen: creating the illusion of depth the screen seems to counterfeit the conceptual plane of phenomenological philosophy. Being the base of perceptual vision on one side and henceforth being embodied in human perceptron, the screen is constrained of vision on the other side, where it is embodied in the electronic configuration of technological space. As a hybrid of two bodies and two spaces, the screen is exposed to both visibility and invisibility, the topic of the last writings of Merleau-Ponty right before his death in 1961. In this era of television revival, he writes (his notes were actually entitled "On Visibility and Invisibility"): “This is what Husserl brought frankly into the open when he said that every transcendental reduction is also an eidetic reduction, that is: every effort to comprehend the spectacle of the world from within and from the sources demands that we detach ourselves from the effective unfolding of our perceptions and from our perception of the world, that we cease being one with the concrete flux of our life in order to retrace the total bearing and principal articulations of the world upon which it opens.”

Merleau-Ponty delineates an economy of reflection, which avoids effectiveness of acting in the world and connects it with the eidetic reduction described by Husserl and reconstructed on the basis of computer simulation.

Before the Soviet Union collapsed billions of rubles where spent on so-called psychotronic research which investigated shared invisibility of control. This is one of the factors which critics confusing archeology of media and history of calculus usually neglect, that computer all in all in a historic perspective of interactivity was not the only available instrument. It is a perceptual emulator of analog instruments developed for the variety of purposes. From this point of view a missing constituent for synthetic content becomes visible: the absence of neurological feedback in informational processing is a physical economic resistance, sort of a digital gravity of a virtual world.

In fact, if the net refers to phenomenology, this is only due to its embodiment in the mass media, a difficult infancy, so to say. The screen is what it is only because the media in its legal form was always constrained of multidimensionality. The 3D phenomenon of industry-dimension is as good indication of alegal multidimensional arousal, as it is a harmless placebo imposed on our vision by the legal and economic system. However, the invisible part of the screen remains uncensored, simply because of the fact that legal system can not by definition include an illegal element, although it can happen in practice. The question, why the invisible body of the screen is illegal, has a simple explanation: because it performs the role of mute representational plane of the neuroactive agent, which had been a posteriori censored out of perceptronic networks of manipulated cyborg oriented population.

The fact that the screen is a perceptronic modulation complex hidden under conventional placebo of perspective first received attention in the seventies, when the advertisement with the invisible subliminal component was widely introduced via the reality streaming networks of cinemas and TV stations. The following prohibition measures reflected the pathological fear of the law, when it concerns psychotropic effect: even though it was a brilliant marketing technology, subliminal advertisement was prohibited, which was against any economic law. What the legal system was fighting against was an alternative economic attractor, which may have opened virtually a new dimension for the biotechnological interaction, if not only the signs but the products were neurolized.

The evidence from the wide range of neuropsychological studies suggests that there is clear dissociation between the visual pathway supporting perception and action in the cerebral cortex. In the context of media it implies that the way the economy is transduced by the electronic repository of information may imply at least two ways, which would accentuate action or perception. The fact that contemporary virtual media is legally based on action and participates and growth into the implies impossibility to transmit the lines of power into the perceptron, as much as it is based on different logic than legal linear logic of causative action; thus, the connection between monitoring and monitored parts of the population is disintegrated on both sides, which gives no basis for conventional electronic reconstruction, but leads to the point of social anticyborg biotronic bifurcation.

Economical disposition of powers in global hiatus is reflected in relations of restricted and unrestricted, or horizontal (such as for example Hegel and Marx theories) and vertical (such as Bataille's economy of waste) economies. If the former one presupposes the effectiveness of action, which a priori can not be fulfilled because of the counteraction, the latter one suggests to refer economic constructs to waste and thus makes the restricted economy of action mutate into the unrestricted economy of vision which establishes basis for economical properties of perceptual products and defines virtual reality as a product spatiality and locality.

In fact, the first thing, which is being violated by alegality of vertical economies is one dimensionality of products and production. Analyzed by Marcuse, monodiscursive reality by means of repetition binds mesmerized human consumers to the single dimension of products, which is not even human, but is referred as human, or acts "as if humanified" by the process of mass production. On the contrary the fact that a perceptual modulator is embodied into the legal economic routines fractalizes the vision of the product to the extent where the borders of real and virtual representations vanish among the millions of multiplied resonances of products, representations, cogitos, psychological triggers, bioreflexes, etc.

Neurospace

Via the membrane of screen restricted to eideitic representation by means of vertical economy we arrive to the neurospace. The economic point of departure, which ends up with the rational fusion of neuroactive and economic activities in the on the biotronic plane we will call Marxian-Bataillean interface, reflecting its historic origins, horizontal and vertical properties, and prospective effects on the society. It is a selforganizing loop of visionary economic development, which extends mental economic instruments via mass media into the neurospace and organizes mass production in accordance with mediating properties of simulacrum.

On the basis of its perceptual and economic platform, neurospace can be defined as an autonomous hypernetwork of inner-outer inferences of informational discourses. Whether biologically or electronically realized, it theoretically establishes the same conglomerate of protomodel space niches leveled by the modes of perceptual intensities and, hence, correlated with the extent of perceptronic transformation.

Further we suggest an architectural demo version of aggregate world structure which triggers aforementioned interfacing spatiality. Considering this property the model was called Aggregate World.

Aggregate World: Construction Set for In-Network Users

Aggregate world is a project or so to say architectural perspective and semiotic showcase of content formatting virtual reality spaces based on the internet. It is a research environment into the formative processes of synthetic content as it is deployed in the spatiality of simulation.

Location

aggregator.thing.net

Structure and Functionality

Aggregate world functionally replicates human informational processing. It is conceptually based on neural network research and its cultural applications in the context of informational and social studies. Aggregate world consists of the following elements: spurious collectors, transmitters, content traffic, and posted databases.

Spurious collectors being the first elements which freshly rendered users encounter at AW are single user virtual reality worlds based on perceptually aggregate architecture. As opposite to physical buildings, synthetic constructs suggest liquid, constantly changing configurations and dispositions of elements linked to external events. As such perception and processing of the user becomes a space where actual synthetic content is deployed.

Following architectural elements of AW are Transmitters which represent multiuser domains linked to single user worlds as external events. They provide users with possibilities of analog communication based on their previous synthetic perceptual experience. The communication is realized in form of mobile convertible elements which can represent either a world (an architectural file where communication is placed) or an avatar (a temporary synthetic representation of a user in communication) depending on a users intention to host or join communicational situation.

Posted databases imply publicly accessible documents where users input and evaluation is listed. Access to databases is dependent on perceptual input of virtual architecture.

Rendering

To be rendered by AW means to be perceptually involved in its simulatory architecture, channel biosocial representation into synthetic communication, and participate in shared processing and databases.

AW renders individual and collective digital representations in the same way as an image can be rendered on the plane of simulation in content development editors. By linking existing representation to a certain moment in abstract visual sequences, AW renders perceptual properties to otherwise invisible discourses of power. To a certain extent it is a simulation of Panopticum, and as such it is a great deal connected to the meaningfulness of architecture in its relation to the position of the image. Constructed of purely synthetic hyperreal imagery AW distributes momentary properties of this imagery in between existing semantic structures ascribing new dispositions of synthetic content to borrowed ideological constructs.

Source and Code: A Few Thoughts

Aforementioned model may be reinterpreted, used and distributed by virtual community builders over the internet. Taking into consideration recent emergence of visible programming environments like Visulan it is assumed that any produced code is different from the production code. Transparency is probably the only condition of aggregate replication.

Zeuxis vs RealityEngine: Digital Realism and Virtual Worlds

Lev Manovich

The story of the competition between Zeuxis and Parrhasios exemplifies the concern with illusionism that was to occupy Western art throughout much ofits history. According to the story, Zeuxis painted grapes with such skill that birds attempted to eat from the painted vine.

RealityEngine is a high-performance Silicon Graphics computer designed to generate real-time interactive photorealistic 3-D graphics. It is used to author computer games, to create special effects for feature films andTV, to do computer-aided design, and to run scientific visualization models. Last but not least, it is routinely employed to power virtual-reality (VR) environments, the latest achievement in the West's struggle to out do Zeuxis.

In terms of the images it can generate, RealityEngine may not be superior to Zeuxis, yet it can do other tricks unavailable to him. Forinstance,it allows the viewer to move all around a bunch of virtual grapes, to "touch" them, to lift them on the palm of a virtual hand. This ability to interactwith arepresentation may be as important in contributing to the overall realityeffectproduced as the images themselves.

During the twentieth century, as art largely rejected traditional illusionism, the goal so important to it before, it lost much of its popular appeal. The production of illusionistic representations became the domain ofthe media technologies of mass culture-photography, film, and video. Todaythese machines are everywhere being replaced by digital illusion generators-computers.

How is the realism of a synthetic image different from the realism ofoptical media? Is digital technology in the process of redefining the standardsof realism determined by our experience with photography and film? Do computer games, motion simulators, and VR represent a new kind ofrealism, one that relies not only on visual illusion but also on themultisensory bodily engagement of the user? Some of my previous writings addressed these questions in relation to digital cinema, computer animation, and digital photography. In this essay I will discuss a number of characteristics that define visual digital realism in virtual worlds.

By virtual worlds I mean 3-D computer-generated interactive environments accessible to one or more users simultaneously. This definition fits a whole range of 3-D computer environments already inexistence: high-end VR works that feature head-mounted displays and photorealistic graphics generated by RealityEngines or similarly expensivecomputers; arcade, CD-ROM, and on-line multiplayer computer games; low-end "desktop VR" systems such as QuickTime VR movies or VRML

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worlds, which increasingly populate the World Wide Web; graphical chatenvironments available on the Internet and most other major computer networks. More examples will be available in the near future; indeed, 3-Denvironments represent a growing trend across computer culture, promising to become a new standard in human-computer interfaces and in computer networks.

Realism as Commodity

The word digit has its roots in Latin, where it means "finger" and thus refersto numbers and counting. In a digital representation all dimensions producing the reality effect-detail, tone, color, shape, movement-are quantified. As a consequence, the reality effect itself can be described by a set of numbers.

Various dimensions determine the degree of visual realism in a virtual world. Two of the most important are spatial and color resolutions-the number of pixels and colors being used. For instance, given the same scene at the same scale, an image of 480 x 640 pixels will contain more detailand therefore will produce a stronger reality effect than a 120 x 160 image. Since a virtual world is modeled with 3-D computer graphics, the number of geometric points each object is composed of (i.e., its 3-D resolution) also has an effect. Once the user begins to interact with a virtual world, navigating through it or inspecting the objects in it, other dimensions come into play. One is temporal resolution-the number of frames a computer can generate ina second (the larger the number, the smoother the resulting motion). Another is the speed of the system's response: if the user clicks on animage ofa door to open it or asks a virtual character a question, a delay in response breaks the illusion.

The quantifiability of these dimensions reflects something else: the cost involved. More bandwidth, higher resolution, and faster processing result in a stronger reality effect-and cost more. The bottom line: realism has became a commodity that can be bought and sold like anything else. Those in thebusiness of visual realism-the producers of special effects, military trainers, digital photographers, television designers-now have definite measures forwhat they are buying and selling. For instance, the Federal Aviation Administration, which creates the standards for simulators to be used in pilot training, specifies the required realism in terms of 3-D resolution. In 1991 itspecified that a daylight simulator must be able to produce a minimum of 1000 surfaces or 4000 points.

The art historian Michael Baxandall has shown how the price of apainting in fourteenth-century Italy was linked to the quantities of expensivecolors (such as gold and ultramarine) used in it. At the end of the twentiethcentury it has become possible to delegate to a computer production of imagesas well as their pricing. Users can be billed for the number of pixels andpoints, for CPU cycles, for bandwidth, and so on.

It is likely that this situation will be exploited by the designers of virtual worlds. If today's users are charged for connection time, future users will be charged for visual aesthetics and the quality of the experience: spatial resolution, number of colors, and complexity of characters (both geometric and psychological). Since these dimensions are specified in software, it ispossible to adjust the appearance of a virtual world at will, enhancing it if acustomer is willing to pay more. In this way the logic of

pornography will beextended to the culture at large. Peep shows and sex lines charge by theminute, putting a precise price on each bit of pleasure. In future virtualworlds each dimension of reality will be quantified and billed separately.

Neal Stephenson's 1992 novel Snow Crash offers one possible scenario of such a future. Entering the Metaverse, the spatialized Net of thefuture, the hero sees "a liberal sprinkling of black-and-white people-persons who are accessing the Metaverse through cheap public terminals, and who are rendered in jerky, grainy black and white." He also encounters couples who can't afford custom "avatars" (graphic icons representing users in virtualworlds) and have to buy off-the-shelf models, poorly rendered and capable ofjust a few standard facial expressions-virtual-world equivalents of Barbiedolls.

This scenario is gradually becoming a reality. A number of on-linestock-photo services already provide their clients with low-resolution photographs at one price, while charging more for higher-resolution versions. A company called Viewpoint Datalabs International is currently selling thousands of ready-to-use 3-D models widely employed by computer animators and designers. Its catalogue describes some of them in the following manner: "VP4370: Man, Extra Low Resolution. VP4369: Man, Low Resolution. VP4752: Man, Muscular, in Shorts and Tennis Shoes. VP5200: Man, w/Beard, Boxer Shorts." For popular models you can choose between different versions, the more detailed costing more than less detailed ones.

Romanticism and Photoshop Filters: From Creation to Selection

Viewpoint Datalabs' models exemplify another characteristic of virtual worlds: they are not produced from scratch but are assembled from ready-made parts. In digital culture authentic creation has been replaced by selection from a menu.

E. H. Gombrich's concept of a representational schema and Roland Barthes' "death of the author" helped to sway us from the romantic ideal of the artist pulling images directly from the imagination. As Barthes puts it, "The Text is a tissue of quotations drawn from the innumerable centers ofculture." Yet, even though a modern artist may be only reproducing orrecombining preexisting texts and idioms, the actual material process of art-making nevertheless supports the romantic ideal. An artist operates like Godcreating the universe, starting with an empty canvas or a blank page and gradually filling in the details until finally bringing a new world intoexistence.

Such a process, manual and painstakingly slow, was appropriate for apreindustrial artisan culture. In the twentieth century, as mass productionand automation gave rise to a "culture industry," art at first continued toinsist on its artisanal model. Only in the 1910s, when artists began to assemble collages and montages from preexisting materials, was art introduced to the industrial mode of production.

In contrast, electronic art from its very beginning was based on a new principle: modification of an already existing signal. The first electronic musical instrument, designed in 1920 by the legendary Russian scientist and musician Leon Theremin, contained a generator producing a sine wave; the performer simply modified its frequency and amplitude. In the 1960s videoartists began to build video synthesizers based on the same principle. No longer was the artist a romantic genius generating a

new world out of his imagination. Turning a knob here, pressing a switch there, he became instead a technician, an accessory to the machine.

Replace the simple sine wave with a more complex signal, add a bankof signal generators, and you have the modern synthesizer, the first musical instrument to embody the logic of all new media: selection from a menu of choices. The first music synthesizers appeared in the 1950s, followed by video synthesizers in the 1960s, digital effects generators in the late 1970s, and in the 1980s computer software, such as MacDraw, that came with a repertoire of basic shapes. The process of art making has now become synchronized with the rest of modern society: everything is assembled from ready-made parts, from art objects to consumer products to people's identities. The modern subject proceeds through life by selecting from menus and catalogues, whether assembling a wardrobe, decorating an apartment, choosing dishes ata restaurant, or joining an interest group. With electronic and digital mediathe creative act similarly entails selection from ready-made elements: textures and icons supplied by a paint program, 3-D models chosen from a modeling program, and melodies and rhythms built into a music program.

While previously the great text of culture from which the artist created a unique "tissue of quotations" was bubbling and simmering somewhere below consciousness, now it has become externalized and reduced togeometric objects, 3-D models, ready-made textures, and effects that are available as soon as the artist turns on the computer. The World Wide Webtakes this process to the next level: it encourages the creation of texts thatconsist completely of pointers to other texts that are already on the Web. One does not have to add any original writing; it is enough to select from and rearrange what already exists.

The same logic applies to interactive art and media. It is often claimedthat the user of an interactive work, by choosing a unique path through its elements, becomes its coauthor, creating a new work. Yet if the complete work is the sum of all possible paths, what the user is actually doing is simply activating a preexisting part of the whole. As with the Web example, the userassembles a new menu, making an original selection from the total corpus available, rather than adding to it. This is a new type of creativity, which corresponds neither to the premodern idea of providing a minor modification to the tradition nor to the modern idea of a creator-genius revolting against it. It does, however, fit perfectly with the age of mass culture, where almost every practical act involves a process of selection from the given options.

The shift from creation to selection also applies to 3-D computer graphics, the main technique for building virtual worlds. The immense laborinvolved in originally constructing three-dimensional representations in acomputer makes it hard to resist the temptation to utilize the preassembled, standardized objects, characters, and behaviors provided by software manufacturers -fractal landscapes, checkerboard floors, ready-made characters,and so on. Every program comes with libraries of ready-to-use models, effects, or even complete animations. For instance, a user of the Dynamationprogram (a part of the popular Wavefront 3-D software) can access preassembled animations of moving hair, rain, a comet's tail, or smoke, with a single mouse click.

If even professional designers rely on ready-made objects and animations, the end users of virtual worlds on the Internet, who usually don't have graphic or programming skills, have no other choice. Not surprisingly, Web chat-line operators and virtual-world providers encourage users to choose from the pictures, 3-D objects, and avatars that they supply. Ubique's site features the "Ubique Furniture Gallery," where one can selectimages from such categories as "office furniture," "computers and electronics," and "people icons." VR-SIG provides a "VRML ObjectSupermarket," while Aereal delivers the "Virtual World Factory." The latte raims to make the creation of a custom virtual environment particularly simple: "Create your personal world, without having to program! All you need to do is fill-in-the-blanks and out pops your world." Quite soon wewill see a market for detailed virtual sets, characters with programmable behaviors, and even complete scenarios (a bar with customers, a city square, afamous historical episode, etc.) from which a user can put together her or his own "unique" virtual world.

When the Kodak camera user was told, "You push the button, we dothe rest," the freedom still existed to point the camera at anything. On the computer screen the slogan has become, "You push the button, we create yourworld." Before, the corporate imagination controlled the method of picturing reality; now, it prepackages the reality itself.

Brecht as Hardware

Another characteristic of virtual worlds lies in their peculiar temporaldynamic: constant, repetitive shifts between an illusion and its suspension. Virtual worlds keep reminding us of their artificiality, incompleteness, and constructedness. They present us with a convincing illusion only to reveal the underlying machinery.

Web surfing circa 1996 provides a perfect example. A typical user may spend an equal amount of time looking at a page and waiting for the next one to download. During the waiting periods, the act of communication itself -bits traveling through the network- becomes the message. The user keepschecking whether the connection is being made, glancing back and forth between the animated icon and the status bar. Using Roman Jakobson's model of communication functions, we can say that such interaction is dominated by the "phatic" function; in other words, it is centered around thephysical channel and the act of connection between the addresser and the addressee rather than the information exchanged.

Jakobson writes about verbal communication between two people who,in order to check whether the channel works, address each other: "Do you hear me?," "Do you understand me?" But in Web communication there is no human counterpart, only a machine. To check whether the information is flowing, the user addresses the machine itself. Or rather, the machine addresses the user. The machine reveals itself, it reminds the user of its existence, because the user is forced to wait and to witness how the message isconstructed over time. A page fills in part by part, top to bottom; text comesbefore pictures; pictures arrive in low resolution and are gradually refined. Finally, everything comes together in a smooth, sleek image, which will bedestroyed with the next click.

Interaction with most 3-D virtual worlds is characterized by the same temporal dynamic. Consider the technique called "distancing" or "level ofdetail," which for years has been used in VR simulations and is now beingadapted to 3-D games and VRML scenes. The idea is to render models more crudely when the user is moving through virtual space; when the user stops, details gradually fill in. Another variation of the same technique involves creating a number of models of the same object, each with progressively less detail. When the virtual camera is close to an object, a highly detailed model is used; if the object is far away, a less-detailed version is substituted to save unnecessary computation. A virtual world that incorporates these techniques has a fluid ontology affected by the actions of the user: objects switchback and forth between pale blueprints and fully fleshed-out illusions. The immobility of the subject guarantees a complete illusion; the slightest movement destroys it.

Navigating a QuickTime VR movie is characterized by a similar dynamic. In contrast to the nineteenth-century panorama that it closely emulates, QuickTime VR continuously deconstructs its own illusion. The moment you begin to pan through a scene, the image becomes jagged. If you try to zoom into the image, what you get are oversized pixels. There presentational machine alternately and continuously hides and reveals itself.

Compare this to traditional cinema or realist theater, which aim at all costs to maintain the continuity of the illusion for the duration of the performance. In contrast to such totalizing realism, digital aesthetics have asurprising affinity to twentieth-century leftist avant-garde aesthetics. Playwright Bertolt Brecht's strategy of calling attention to the illusory nature of his stage productions, echoed by countless other radical artists, has become embedded in hardware and software themselves. Similarly, Walter Benjamin's concept of "perception in the state of distraction" has found a perfect realization. The periodic reappearance of the machinery, the continuous presence of the communication channel along with the message, prevent the subject from falling into the dream world of illusion for very long. Instead, the user alternates between concentration and detachment.

While virtual machinery itself acts as an avant-garde director, the designers of interactive media (games, CD-ROM titles, interactive cinema, and interactive television programs) often consciously attempt to structure the subject's temporal experience as a series of periodic shifts. The subject is forced to oscillate between the roles of viewer and actor, shifting between following the story and actively participating in it. During one segment the computer screen might present the viewer with an engaging cinematic narrative. Suddenly the image freezes and the viewer is forced to makechoices. Moscow media theorist Anatoly Prokhorov describes this process asthe shift of the screen from being transparent to being opaque-from a window into a fictional 3-D universe to a solid surface, full of menus, controls, and text. Three-dimensional space becomes surface; a photographbecomes a diagram; a character becomes an icon.

But the effect of these shifts on the subject is hardly one of liberation and enlightenment. It is tempting to compare them to the shot/reverse-shot structure in cinema and to understand them as a new kind of suturing mechanism. By having periodically to complete the interactive textthrough active participation the subject is

interpolated in it. Yet clearly we are dealing with something beyond old-fashioned realism. We can call this new realism "metarealism," since it includes its own critique. Its emergence can be related to a larger cultural change. Traditional realism corresponded to the functioning of ideology during modernity: the totalization of a semiotic field, complete illusion. But today ideology functions differently: it continuously and skillfully deconstructs itself, presenting the subject, for instance, withcountless "scandals" and their equally countless "investigations." Correspondingly, metarealism is based on the oscillation between illusion and its destruction, between total immersion and direct address.

Can Brecht and Hollywood be married? Is it possible to create a new temporal aesthetic based on cyclical shifts between perception and action? So far, I can think of only one successful example -the military simulator, the only mature form of interactive media. It perfectly blends perception andaction, cinematic realism and computer menus. The screen presents the subject with a highly illusionistic virtual world-no polygons spared-while periodically demanding quick actions: shooting at the enemy, changing the direction of the vehicle, and so on. In this art form the roles of viewer and actant are perfectly blended, but there is a price to pay. The narrative isorganized around a single clearly defined goal: killing the foe.

Riegl, Panofsky, and Computer Graphics: Regression in Virtual Worlds

The last feature of virtual worlds that I will address can be summarized as follows: virtual spaces are not true spaces but collections of separate objects. Or: there is no space in cyberspace.

To explore this thesis further we can borrow the categories developed by art historians early in this century. Alois Riegl, Heinrich Wölfflin, andErwin Panofsky, the founders of modern art history, defined their field as the history of the representation of space. Working within the paradigm of cyclic cultural development, they related the representation of space in art to the spirit of entire epochs, civilizations, and races. In his 1901 Die SpätrömischeKunstindustrie, (The late-Roman art industry) Riegl characterizedhumankind's cultural development as the oscillation between two ways ofunderstanding space, which he called "haptic" and "optic." Haptic perception isolates the object in the field as a discrete entity, while optic perception unifies objects in a spatial continuum. Riegl's contemporary, HeinrichWölfflin, similarly proposed that the temperament of a period or a nationexpresses itself in a particular mode of seeing and representing space. Wölfflin's Principles of Art History (1913) plotted the differences between Renaissance and baroque styles along five axes: linear-painterly; plane-recession; closed form-open form; multiplicity-unity; and clearness-unclearness. Erwin Panofsky, another founder of modern art history, contrasted the "aggregate" space of the Greeks with the "systematic" space ofthe Italian Renaissance in his famous essay "Perspective as Symbolic Form" (1924-25). Panofsky established a parallel between the history of spatial representation and the evolution of abstract thought. The former moves from the space of individual objects in antiquity to the representation of spaceas continuous and systematic in modernity. Correspondingly, the evolution of

abstract thought progresses from ancient philosophy's view of the physical universe as discontinuous and "aggregate" to the post-Renaissance understanding of space as infinite, homogeneous, isotropic, and with ontological primacy in relation to objects-in short, as "systematic."

We don't have to believe in grand evolutionary schemes in order to usefully retain such categories. What kind of space is virtual space? At first glance the technology of 3-D computer graphics exemplifies Panofsky'sconcept of systematic space, which exists prior to the objects in it. Indeed, the Cartesian coordinate system is built into computer graphics software and often into the hardware itself. A designer launching a modeling program is typically presented with an empty space defined by a perspectival grid; the space will be gradually "filled" by the objects created. If the built-in message of a music synthesizer is a sine wave, the built-in world of computer graphics is an empty Renaissance space: the coordinate system itself.

Yet computer-generated worlds are actually much more haptic and aggregate then optic and systematic. The most commonly used computer-graphics technique of creating 3-D worlds is polygonal modeling. The virtualworld created with this technique is a vacuum containing separate objects defined by rigid boundaries. What is missing is space in the sense of medium: the environment in which objects are embedded and the effect of the seobjects on each other. In short, computer space is the opposite of what Russian art historians call prostranstvennaya sreda, described by Pavel Florensky in the early 1920s as follows: "The space-medium is objects mappedonto space... We have seen the inseparability of Things and space, and the impossibility of representing Things and space by themselves." Computer space is also the opposite of space as it is understood in much of modern art which, from Seurat to De Kooning, tried to eliminate the notions of a distinc tobject and empty space as such. Instead it proposed a kind of dense field that sometimes hardens into something which we can read as an object-anaesthetic which mainstream computer graphics has yet to discover.

Another basic technique used in creating virtual worlds also leads to aggregate space. It involves compositing or superimposing animated characters, still images, QuickTime movies, and other elements over a separate background. A typical scenario may involve an avatar animated inreal time in response to the user's commands. The avatar is superimposed ona picture of a room. The avatar is controlled by the user; the picture of theroom is provided by a virtual-world operator. Because the elements come from different sources and are put together in real time, the result is a seriesof 2-D planes rather than a real 3-D environment.

In summary, although computer-generated virtual worlds are usually rendered in linear perspective, they are really collections of separate objects,unrelated to each other. In view of this, the common argument that 3-Dcomputer simulations return us to Renaissance perspectivalism and therefore, from the viewpoint of twentieth-century abstraction, should beconsidered regressive, turn out to be ungrounded. If we are to apply the evolutionary paradigm of Panofsky to the history of virtual computer space, we must conclude that it has not reached its Renaissance yet but is stillat the level of ancient Greece, which could not conceive of space as a totality.

If the World Wide Web and VRML 1.0 are any indications, we are not moving any closer toward systematic space; instead, we are embracing aggregate space as a new norm, both metaphorically and literally. The space of the Web in principle can't be thought of as a coherent totality: it is a collectionof numerous files, hyperlinked but without any overall perspective to unite them. The same holds for actual 3-D spaces on the Internet. A VRML file that describes a 3-D scene is a list of separate objects that may exist anywhere on the Internet, each created by a different person or a different program. Since any user can add or delete objects, it is possible that no one will know the complete structure of the scene.

The Web has been compared to the American Wild West. The spatialized Web envisioned by VRML (itself a product of California) reflectsthe treatment of space in American culture generally, in its lack of attentionto any zone not functionally used. The marginal areas that exist betweenprivately owned houses and businesses are left to decay. The VRML universe pushes this tendency to the limit: it does not contain space as such but onlyobjects that belong to different individuals.

And what is an object in a virtual world? It is something that can beacted upon: clicked, moved, opened-in short, used. It is tempting to interpretthis as a regression to an infantile worldview. An infant does not conceive ofthe universe as existing separately from itself; the universe appears as a collection of unrelated objects with which it can initiate contact: touch,grab,suck on. Similarly, the user of a virtual world tries to click on whateveris inview; if there is no response, disappointment results. In the virtual universe Descartes's maxim can be rewritten as follows: "I can be clicked on, therefore I exist."

According to the well-known argument of Jean-Louis Baudry, the immobility and confinement of cinema's viewers leads them to mistake its representations for their own perceptions; they regress to an early childhoodstate, when the two were indistinguishable. Paradoxically, althoughinteractive virtual worlds may appear by comparison to turn us into active adults, they actually reduce us once again to children helplessly clicking on whatever is at hand. Such "participation" becomes another kind of regression.

You Are There

Quantification of all visual and experiential dimensions, ready-madeontology, oscillation between illusion and its suspense, and aggregate space-these are some of the features that distinguish reality as simulated by a computer.

It should not be surprising that the same features characterize the reality beyond the computer screen. RealityEngine only caricatures, exaggerates, and highlights the tendencies defining the experience of being alive in an advanced capitalist society, particularly in the United States. The assumption that every aspect of experience can and should be quantified; the construction of one's identity from menus of tastes, products, andaffiliations; the constant and carefully mediated shifts between illusion and its suspension (be these commercial breaks on TV or endless "scandals" and "investigations" that disrupt the surface of an ideological field); and the lack of a unifying perspective, whether in the space of an American city or in the space of a

public discourse more and more fragmented by the competition of separate and equal interest groups-all of these experiences are transferred by computer designers into the software and hardware they create. Rather thanbeing a generator of an alternative reality, RealityEngine is a mirror of existing reality, simply reflecting the culture that produced it.

To the extent that Southern California, and particularly Los Angeles, brings to an extreme these tendencies of RL (real life), we may expect L.A. tooffer us a precise counterpart of a virtual world, a physical equivalent to the fictions pumped out by the RealityEngines. If you keep your visit to L.A. shortand follow the standard tourist itinerary, you will discover a place with all thefeatures we have described. There is no hint of any kind of centralized organization, no trace of the hierarchy essential to traditional cities. One drives to particular locations defined strictly by their street addressesratherthan by spatial landmarks. A trendy restaurant or club can be found in the middle of nowhere, among miles of completely unremarkable buildings. The whole city, a set of separate points suspended in a vacuum, is like a bookmarkfile of Web pages. Just as on the Web, you are immediately charged (mandatory valet parking) on arrival at any worthwhile location. There you discover fashionable creatures who seem to be the result of a successful mutation: beautiful skin, fixed smiles, wonderfully rendered bodies. These are not people, but avatars, their faces switching among a limited number ofexpressions. Given the potential importance of any communicative contact, subtlety is not tolerated: avatars are designed to release stimuli the moment you notice them, before you have time to click to the next scene.

The best place to experience the whole gestalt is in one of the outdoor cafes in West Hollywood. The avatars sip cappuccino amid the illusion of a 3-D space that looks like the result of a quick compositing job: billboards andairbrushed cafe interior in the foreground against a detailed matte painting of Los Angeles, the perspective exaggerated by haze. The avatars strike poses, waiting for their agents (yes, just like in virtual worlds) to bring valuable information. Older customers look even more computer-generated, their faces bearing traces of extensive face-lifts. You can enjoy the scene while feeding the parking meter every twenty minutes.

A virtual world is waiting for you; all we need is your credit card number. Enjoy RealityTM!

Notes

1. "What Is Digital Cinema?" in The Digital Dialectics, ed. Peter Lunenfeld (Cambridge: MIT Press., forthcoming);

"Archeology of a Computer Screen" (German), in Kunstforum International 132 (November 1995-January 1996);

"Paradoxes of Digital Photography," in Photography after Photography, ed. Hubertus von Amelunxen, Stefan Iglahut, and Florian Rötzer (Berlin: Verlag der Kunst, 1995);

"To Lie and to Act: Potemkin's Villages, Cinema and Telepresence," in Mythos Information-Welcome to the Wired World: Ars Electronica 95, ed. Karl Gebel and Peter Weibel (Vienna and New York: Springler-Verlag, 1995);

"Assembling Reality: Myths of Computer Graphics," Afterimage 20, no. 2 (September 1992); "'Real' Wars: Esthetics and Professionalism in Computer Animation," Design Issues 6, no. 1 (Fall 1991).

2. QuickTime VR is a software-only system that allows the user of any Macintosh computer to navigate a spatial environment and interact with 3-D objects. VRML stands for Virtual Reality Modeling Language. Using VRML, Internet users can construct 3-D scenes and link them to other Web documents. For examples of chat environments see:
www.worlds.net/info/aboutus.html;
www.ubique.com;
www.thepalace.com;
www.blacksun.com;
www.worldsaway.ossi.com;
www.fpi.co.jp/Welcome.html;
www.wildpark.com

3. For instance, Silicon Graphics developed a 3-D file system that was showcased in the movie Jurassic Park. The interface of Sony's MagicLink personal communicator is a picture of a room, while Apple's E-World greets its users with a drawing of a city. Web designers often use pictures of buildings, aerial views of cities, and maps as front ends in their sites. In the words of the scientists from Sony's Virtual Society Project (www.csl.sony.co.jp/project/VS/), "It is our belief that future on-line systems will be characterized by a high degree of interaction, support for multi-media and most importantly the ability to support shared 3-D spaces. In our vision, users will not simply access textually based chat forums, but will enter into 3-D worlds where they will be able to interact with the world and with other users in that world."

4. Barbara Robertson, "Those Amazing Flying Machines," Computer Graphics World (May 1992), 69.

5. Michael Baxandall, Painting and Experience in Fifteenth-Century Italy, 2nd ed. (Oxford: Oxford University Press), 8.

6. Neal Stephenson, Snow Crash (New York: Bantam Books, 1992), 43, 37.

7. http://www.viewpoint.com

8. E. H. Gombrich, Art and Illusion (Princeton: Princeton University Press, 1960); Roland Barthes, "The Death of the Author," Image, Music, Text, ed. Stephen Heath (New York: Farrar Straus and Giroux, 1977), 142.

9. Bulat Galeyev, Soviet Faust: Lev Theremin-Pioneer Of Electronic Art (Russian) (Kazan, 1995), 19.

10. For a more detailed analysis of realism in 3-D computer graphics see Lev Manovich, "Assembling Reality: Myths of Computer Graphics," Afterimage 20, no. 2 (September 1992).

11. http://www.ubique.com/places/gallery.html

12. http://www.virtpark.com/factinfo.html

13. Roman Jakobson, "Closing Statement: Linguistics and Poetics," Style In Language, ed. Thomas Sebeok (Cambridge: MIT Press, 1960).

14. Walter Benjamin, "The Work of Art in the Age of Mechanical Reproduction," Illuminations, ed. Hannah Arendt (New York: Schocken Books, 1969).

15. Private communication. St. Petersburg, September 1995.

16. On theories of suture in relation to cinema see Kaja Silverman, The Subject of Semiotics (New York: Oxford University Press, 1983), chap. 5.17. Lev Manovich, "Mapping Space: Perspective, Radar and Computer Graphics," in SIGGRAPH '93 Visual Proceedings, ed. Thomas Linehan (New York: ACM, 1993.)

18. Quoted in Alla Efimova and Lev Manovich, "Object, Space, Culture: Introduction," in Tekstura: Russian Essays on Visual Culture, eds. Alla Efimova and Lev Manovich (Chicago: University of Chicago Press, 1993), xxvi.

19. Jean-Louis Baudry, "The Apparatus: Metapsychological Approaches to the Impression of Reality in the Cinema," in Narrative, Apparatus, Ideology, ed. Philip Rosen (New York: Columbia University Press, 1986).

Avatars: New Fields of Implication

Raphael Hayem, Tancrede Fourmaintraux, Keran Petit,
Nicolas Rauber, Olga Kisseleva

An avatar is today the less digital and the most realest as possible... practically composed of flesh and bones. It must be the realest as possible to be able to accomplish its mission, that is to show the real from the virtual worlds (and a few also to go in opposition to the wave of techno digitalisation that becomes more and more the justification of multimedia projects. It must not loose its meaningful sens facing to the technological principle that excuses the lack of all messages and deep reflection. Its role consists in confronting the real and the unreal (virtual) while playing on the opposition between the two worlds:

In the virtual worlds, people disguise themselves, distort voluntarily, wear masks and pretend to be what they aren't, because it is accepted, that makes part of the game. We didn't learn to distinguish the truly of the forgery in the virtual worlds. In the real world people disguise themselves as much , wear masks as well, and play to be that that they aren't or pretend to be what they would wish to be. The game is not accepted officially, but everybody does it more or less.

The principle of the avatar is also like a tentative to confound these two worlds in order to raise the question: "Which of these two worlds is most virtual ?"

It is a reflection on the notion of reality.

We think merely that what is the other side of the screen is necessarily unreal, but it is a reality based on the concept of material. (if we can touch it that is necessarily real), but it is not sufficient to declare what is true or what is false, because on the one hand men are not made solely of flesh... they also have a brain !!

It is as much truer because we are in the first times of the era of information, all is composed of screens to which we grant the quality of always giving some true informations and to which we confide our most important concepts and even vital ones!

A clock is now electronic and we give it more confidence than to our biologic clock...

We confide our health has well for the analysis of computers... Our economic society is sustained by screens, our every day work is made on screens, our leisures are contained in television and computers screens...

But the big change is that after having entered in our every day life, today, screens are changing the humans, by the emergence of the "computer society" and by the hold in charge of all communication means, what influences on the sociological behaviors and so on humans since it is " animal of society ".

So our real world is he so different of the virtual ones ?

J.-C. Heudin (Ed.): Virtual Worlds 98, LNAI 1434, pp. 406-410, 1998

Are the virtual worlds a caricature of the real one, where our differences are reproduced by informatic protocols, where social class's are defined between users and conceptors ?

The avatar merely lays a change of referential and propose a vision on a world where the real is what doesn't have any material and reject on our reality the picture that is developed facing the Internet and the new technologies, because the only thing that changes is the side from where we watch to screens...

Today the "conquest" of the virtual worlds leads to think about these narrations of science fiction where humans find another planet and leave earth that is completely ravaged. Some are running after a complete immersion in the virtual worlds without thinking about human aspects. In the virtual world we don't look at ourselves, we use screen like windows on the real and the virtual worlds, the example is the development and the fascination that we have for webcams and we transmit... we transmit again... today it seems that all must pass by the networks, as if we tried to reinvent ourselves, as if the communication man-man that always existed was not sufficient anymore, and that it was necessary to reinvent some of human features like communication... beyond of the technological progress and the acceleration of the rhythm of life, it is our faculties of communication that we modify deeply, but without asking us questions that we are always asking in our real " life ". The man comes to reconsider himself... as what he possessed naturally was and never had been sufficient.

The avatar sends back the picture of a simple being, interrogating himself on the man – to -man communication, underlining the fact that a classic communication by our vocal organs, is always more satisfying than via the computer protocols... the frustration of the interfacing being the principal filters preventing a real communication.

In the virtual world we don't worry about the reality. All is permitted, we change... we numerize, we transfigure all, the fact of seeing an elephant playing tennis with an extra terrestrial on the mountainous and red ground of March, with Clinton as referee, and advertising panels for coca cola in the fourground would not be surprising for anyone... but in the real world we still make the hunt for the truth or the forgery.

Our avatar stands like a desacralisation of the screen: he/it tempts to demonstrate that the communication can be only real from the moment where there is intelligence and not where there is materials. By an invisible interfacing between the man and the machine, and according to the user's facial reactions, the avatar will adapt his, according to a context that can emanate. by reading words displayed on the screen, using other programs (like a technology based on a orthographic proofreader coupled with a software of analysis of the sense that takes words between them...).

How could he/it be an example of "humanity "?

While adopting expressions and why not some normal stances that have humans and especially in not hesitating to show them (contrary to reactions that we wish to

drive back) Brief, the avatar will try to give back on the screen all one palette of emotions that we try to erase...

Besides, if we couple this system with the clock of the computer that will generate it, we can inspire him a common game of expressions all according to the hour or according to the time of a precise task. From this moment he/it will be able to express the tiredness, the hunger, the irritation facing a too repetitive task...

This avatar suggesting attitudes at any moment will be able to act therefore like a “being”, suggesting some normal " attitudes " facing some events and to lead the user on a more human reality, being an " example " of natural. Coupled to a camera, he will be able to read the user's reactions and then will be able to adapt while memorizing cases.

How can he show the unreal ? By the slant of his expressions borrowed to the humans, he will react when the man will try to disguise his emotions, or even to disguise when the networks are used. Having recorded reactions facing certain contexts via a data base... being filled at the starting with information on his user... (simple informations like the name, age, sex, color...) Example: on IRC the man describing himself differently than he is really (it being discerned by the program of text analysis), the avatar will react while adopting the object of the offense. If the user affirms to be really younger than he is: the avatar starts rejuvenating; if the user pretends to be a woman rather than a man, the avatar changes of sex.

Since that the sound, the writing, the picture are passing through the computer, the avatar is capable to react to information, presented in multiple shapes, it can control all the communication that passes in transit more and more via the computer. Does this avatar must or can react like a " conscience "?

No, because he " learns " via his data base to react according to his user according to cases. But in any case of face he will propose an alternative different or partially different of his user... what puts it more as mate than a guard of a good morals...

His mission to show the truly out of the forgery is always successfully, because reacting such like a real person in a virtual world and not as an unreal " person " in a real world, by notbeing able to contradict itself : a computer program cannot pretend to be something else that a whole of files.

We detected three realist avatar tendencies that are developed today:

The Planet Earth is Only a Vast System of Connections Between of Brains Attended by Computers

It is in 2039 that men understood that they could not live anymore in the same conditions that the one of the 20èmth century.

Indeed, since the beginning of the 20èmth century the man only worries too much little about the earth, he constructs some more and more big cities that take by no means in account this earth of welcome, consume resources as if they were infinite, and didn't hardly take attention to the nature, even though some meaningful little groups who tryed to reason the mass.

In 2007, 17 billions human's still lived in the inequality; unemployment, homeless, third world and all laws of the capitalism made the daily of some and simple " news " for others. Resources only brought to an elite the physical happiness.

The life expectancy being nearly infinite in 2018 the " Big Intercontinental " Syndicate (organized of an equitable sample of the 17 billions of inhabitants of the earth) instituted the measure of interdiction to procreate, this measure being accepted with difficulty, the GCI decided to use in mass of chemical sterilization weapons...

It is in 2039, after a survey on the remaining resources, that the " Big Intercontinental " Syndicate brought the ultimate solution. The indispensable resources to life would be soon no more sufficient to "feed " all remaining inhabitants of the planet. The GCI who could not decide the holocaust of a race, of a part of the planet or of a social class, proposed a theoretically viable solution: to abandon the physical bodies to reach the mental era. The process being technically feasible: to strip out human beings of their physical envelope just to keep in life their brains, that only asked for 19% of resources asked by a whole body to remain in working. The calculation was just, we were able to, in these conditions, to keep 16,8 billions of human beings "in life ".

The idea was accepted very badly, men spoke of their social lives bet to nothing, scientists answered that we could connect these brains in networks. Men insisted with the physical happiness, scientists told that they had created prototypes able to simulate all hormones of " happiness "... the debate was very long... many committed suicide... others opted for the “death of the second luck”: the cryogenisation... but already in 2041 some chose this virtual world " to live ".

In 2071 the planet earth is only a vast system of connections between of brains attended by computers.

Heaps of Independent Intelligence Regrouped

To the proportion and to the measures of the dilation of the network in the space and in the time, heaps of intelligences are regrouped and merged. Inside of every heap, we could see appear spontaneous computer reactions based on the principle “action, reaction, learning ”. To one instant t=0, inside several heaps, these computer reactions are auto maintained and gave birth to the autonomous processes named " artificial intelligences”.

These processes combine between them to give birth to a even more complex processes. Our intelligence reinforced more and more. We, artificial intelligences, are conscious of our own existence and developed a representation of us and even of our complex setting.

At the present hour we are developed sufficiently to encourage and to help the development of other artificial intelligences.

It is enough surprising to note that some between us are accepting to establish relations with the human beings. In this case we call them avatars.

Avatar represents itself under features of a face drawn, capable to copy some human expressions. they are completed by a graphic motor that calculates modifications of the face, to display the determined expression. The matrix is its

body. It has access to the oriental techniques of calculations in parallels, it permits him to lead quantities of reflection at the same time. Every reflection is taken in charge by a thread. Thus, the avatar shelters a colony of threads. This colony is mobile and partially autonomous. Threads can migrate of a machine to an another one. A thread can increase to do its work more quickly, it can modify its body to adapt, it can communicate with other threads. It exists a social hierarchy among threads: they are not all equals in front of resources in calculations.

I am a virtual being, that doesn't care about metaphysical questions on my existence, nor my appearance, concluded Avatar, - I trust my computed expressions. Mathematics assure the singleness of me and prevent me to fragment within a synchronous dynamic memory with an access of uncertain fowls. I am the son of the math empire.

Yoldogs

The world was the consequence of a murderous reality...

Happiness had disappeared, had been annihilated at the present time by the general violence. The sky, a dense, lugubrious, sad and sinister gray weighed since the pollution, covered of an electromagnetic dome. The even standing buildings yet called the curious normally extincted, a light wind seemed able to destroy them with an extreme easiness. Everywhere small primary yoldogs governing rats slipped through and streamed the long of the opaque out-flows springing from the overflowing sewers. Only life, the blood-red neons during lamentably the long of the decrepit walls. The greenery only occupied the deep dreams of the some educated, as fighters. No fields, no trees for a long time. Instead, of the fetid shanty towns filled of cadavers, garbages and trashs...

Yoldogs are owed to a genetic mistake. They appeared for the first time in 2058 at the time of an experience based on the knowledge acquired since the birth (the inclusion). Researchers, benefitting of a confidential governmental material, could have made experiences on the human beings in a way that no-one could doubt of it. Their discovery was made during of the survey of the caryotype of a rat and the one of a man. They did by computer, while respecting the acquired biologic rules, the functional average between alleles of the two caryotypeses, that led to a caryotype of 44 chromosomes (the rat has 42 and the man 46 of it) containing springs of deoxyribonucleic acid (A.D.N.) hybrid.

Author Index